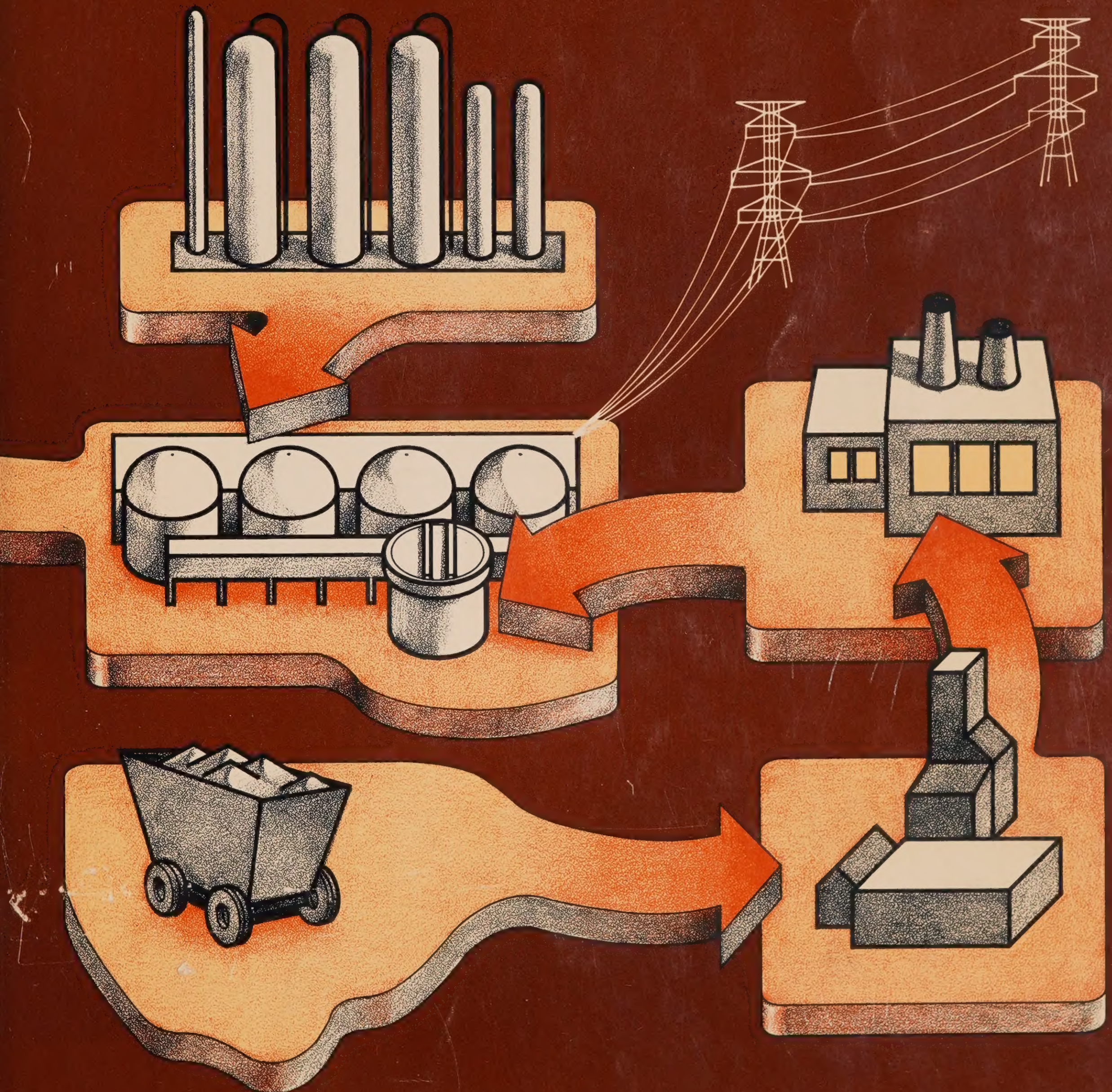
A Race Against Time



Royal Commission on Electric Power Planning

INTERIM REPORT ON NUCLEAR POWER IN ONTARIO

Ontario

ROYAL COMMISSION

ON

ELECTRIC POWER PLANNING

CHAIRMAN: ARTHUR PORTER

INTERIM REPORT

ON

NUCLEAR POWER IN ONTARIO

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12 September 1978

The Honourable Rene Brunelle
Provincial Secretary for Resources Development
Legislative Building
Room 180
Queen's Park
TORONTO, Ontario

Dear Mr. Minister:

Pursuant to Order-in-Council #3489/77 dated 14 December 1977 requesting the Commission to complete the examination of issues relating to nuclear power and to prepare an interim report on its opinions and conclusions, and the Commission having completed these duties, I have pleasure in submitting herewith the said interim report.

Yours very truly,

Arthur Porter

Arthur Porter
Chairman

Royal Commission
on
Electric Power Planning

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Compendium of Major Findings

In December, 1977, the Commission was directed by Order-in-Council to prepare an interim report on the nuclear power issue. This summary presents in a concise manner our major findings. They are predicated on 335 hours of public debate, on many submissions, on in-depth studies and on investigations we have conducted in Ontario and in other jurisdictions.

Not surprisingly, the major concerns of critics of nuclear power relate to the health, environmental, safety, economic and political aspects of nuclear power rather than the scientific and technological. To many, nuclear power represents the embodiment of "hard" as contrasted with "soft", technology, the increasing centralization of electric power, and concomitantly, the increasing centralization and dehumanization of society as well as threats to the biosphere. To the proponents, nuclear power is essentially an everlasting source of clean energy that will become increasingly important as oil stocks rapidly dwindle towards the end of the century. They view it as a technology necessary for our social and economic well-being. Virtually all participants in the nuclear debate, however, have agreed with the conclusion of the World Council of Churches Study Group that "Pandora's box cannot be closed. We cannot live as though nuclear power had not been discovered."

In Ontario, as of the end of 1977, 3800 MW of nuclear power was already installed and operating and another 10,000 MW is under construction. Indeed, during 1977 the installed nuclear capacity in the province accounted for 27 per cent of total electrical energy generated even on the basis of a comparatively low (70 per cent) capacity factor. Furthermore, based on Ontario Hydro's latest system expansion programme, about 80 per cent of the province's electricity would be supplied by nuclear power stations by the end of the century.

Nuclear power in the province is based on the CANDU reactor, a reactor which on a fuel utilization basis has to date proved to be the most efficient commercially available. CANDU is, of course, the principal actor in this report. It is not, however, considered in isolation but rather as a major component in the nuclear fuel cycle.

Since its inception, the Commission has been particularly conscious of the need to develop realistic estimates of the future demand for electricity. We have therefore reviewed many forecasting models and conducted our own appraisal of the major determinants of electricity growth. As a result, we have concluded that electricity demand will grow at a rate between 2 and 6 per cent to the year 2000 with the most probable rate being about 4 per cent. This growth rate will, of course, be significantly influenced by the oil supply situation, by the trend towards the more efficient utilization of energy through conservation and co-generation, and not least by our increasing reliance on solar energy in all its manifestations, particularly solar thermal, biomass and hydraulic energy. If Ontario Hydro is to service the additional load with a

reasonable level of reliability, then some expansion of bulk power generation before the year 2000 is inevitable. We have concluded that nuclear power has a role to play in this expansion programme. In assessing its future role we have considered the following factors: health, environmental and safety concerns; the economics of nuclear power; social impacts and the status of the nuclear industry; uranium resources; social, ethical and political issues; nuclear weapons proliferation and plant security; regulation of nuclear power; alternative supply technologies and the future of nuclear power in Ontario.

Health, Environment and Safety

- The absolute safety of any industrial process, or human activity, including the generation of electricity, cannot be guaranteed. In the case of the CANDU reactor we have concluded that, within reasonable limits, the reactor is safe. However, the need for continual vigilance and reassessment of reactor safety systems by Ontario Hydro cannot be overemphasized.
- The radioactive releases during the normal operation of a CANDU power station should not give rise to concern.
- The analyses of loss of regulation incidents, the unavailability of the emergency core cooling systems and the loss of containment incidents by Ontario Hydro and Atomic Energy of Canada Limited have, in our opinion, led to improvements and enhanced reliability.
- Technology, per se, cannot be endowed with an "ultimate defence" against accidents; this must rest with human operators. For this reason the training and skill-maintenance procedures for nuclear operators should be upgraded.
- Criticism of various aspects of reactor operations by workers should be encouraged.
- The evaluation of safety measures should take into consideration the economic implications.
- Research on reactor safety should not be downgraded in the interest of other nuclear reactor research, especially in the advanced fuel cycles area.
- The off-site contingency plans should be reviewed; there should be at least annual full scale rehearsals and the reports of the rehearsals should be made public.
- The concept of large dedicated nuclear sites has much to commend it on health, environmental and safety grounds.
- Spent fuel reprocessing and advanced fuel cycles should not be part of Ontario Hydro's system planning to the year 2000. Hence, there is no need for a central interim

storage facility for spent fuel. All spent fuel should be stored at nuclear generating station sites, either in circulating water storage bays or in "dry storage" if this proves feasible.

• The sale of irradiated (spent) fuel after a suitable period in on-site storage is an option which should be explored.

• Suitable sites for the ultimate disposal of spent fuel and other high-level radioactive wastes should be identified on the basis of both technical and social acceptability. These sites should satisfy the most rigorous geological and ecological criteria. Research and demonstration to these ends should be of the highest priority. Ontario citizens who may be affected in any way should be consulted during all stages of the process.

• An independent review committee should be established to report to the Atomic Energy Control Board (AECB) on progress on waste disposal research and demonstration. If the committee is not satisfied with progress by 1985, a moratorium on additional nuclear power stations would be justified.

• Uranium mill tailings will constitute an increasing health and environmental problem. An independent review committee should be established to study the problem in depth and prepare a public report for the AECB and the Ontario Environmental Assessment Board. The future of the nuclear programme should be assessed in light of the committee's findings and progress in mill tailings containment technology.

The Economics of Nuclear Power

• On economic grounds CANDU nuclear and coal generation are the major realistic options for new large scale base load supply of electricity in Ontario in the late 1980s and 1990s.

• CANDU units in the 850 MW capacity range are the obvious economic choice for Ontario Hydro's base load generation. On the evidence presented to date, the 1250 MW CANDU reactor should not be adopted by the utility until the turn of the century at the earliest.

• Once constructed, nuclear power with its high capital costs and low operating costs, is less susceptible than coal to inflation and relatively insensitive to fuel costs. The fuel cost ratio of nuclear power to coal power per kWh generated is roughly 1:9.

• New nuclear generating stations based on a load growth of 4 per cent and 6 per cent per annum to the year 2000 involve capital expenditures ($2000/kW current dollars) of approximately $25 billion and $60 billion respectively.

• The difficulties of obtaining sufficient capital for a major nuclear programme are

serious enough that capital availability should be considered as an important constraint in assessing the proportion of nuclear power in the generation mix.

• Appropriate sinking funds should be established to defray at least half of the expected decommissioning costs for nuclear stations and to defray the future costs for spent fuel management and disposal. These costs should be incorporated into current electricity rates.

• Prior to committing further nuclear capacity, the likely shape of the system load curve should be carefully reviewed and if this review indicates greater uncertainty in the relative need for base load capacity, other generating options (such as fossil or hydraulic capacity) which are more operationally flexible than nuclear power should be adopted.

• Research and development costs for nuclear power should be included in the accounting when comparing the nuclear option to renewable energy alternatives.

Social Impacts and the Status of the Nuclear Industry

• The suggestion that Ontario Hydro's financial requirements will "draw capital away" from other social needs is oversimplified.

• The nuclear components industry in Canada faces serious under-utilization of its capacity. Based on the recent reduced Canadian forecasts, it is unlikely that the domestic market could fill the gap, making exports important to the continued well-being of the industry.

• The export potential for CANDU is uncertain. Markets in the industrialized world probably will take the form of licensing arrangements which will be of little benefit to the domestic industry in the long term and may result in offshore competitors for future CANDU exports.

• Exports of CANDU reactors to industrialized countries could be made more attractive by giving potential buyers preferred access to supplies of Canadian uranium. Depending on the nature of such agreements, the availability of uranium resources and more importantly, production capacity for domestic use may be negatively affected.

• CANDU plants built in Canada and dedicated to the export of power to the United States deserve further study in light of arguments "for" and "against" this proposal.

• If CANDU sales outside Ontario do not materialize, the consequences are difficult to predict; suppliers might be limited and the cost of components to Ontario Hydro might rise.

• Many of the factors which will influence the future health of the nuclear components industry are beyond the direct control of the Government of Ontario.

Uranium Resources

• Canada possesses approximately 20 per cent of the western world's currently estimated total uranium resource potential.

• The projected growth in world nuclear power and the concomitant uranium requirements, particularly those of our major allies and trading partners, are of considerable consequence to the future role of nuclear energy in Canada and Ontario.

• The recently approved Ontario Hydro uranium contracts, plus existing export commitments, already more than exhaust Ontario's currently estimated reasonably assured uranium resources in the measured and indicated categories.

• In evaluating the status of the uranium resource base, it is absolutely critical to consider whether all of this potential resource can in fact be made "physically available" at a rate corresponding to the increasing demand.

• A small nuclear programme in Ontario — perhaps an additional commitment beyond Darlington of a few thousand MW — could be fuelled from production indigenous to Ontario, assuming no further exports, to well beyond 2000.

• Neither the currently known uranium resource base, in Canada and Ontario, nor the projected maximum production capacities likely to be available for Ontario use are sufficiently secure to guarantee the long term viability of a large "once-through" nuclear power programme in Ontario. We are not, however, prepared to endorse the inclusion of advanced fuel cycles in Ontario Hydro's system planning at this time.

• Many of the factors which will influence the price and availability of uranium resources and production capacity to Ontario Hydro are beyond the direct control of the Government of Ontario.

Social, Ethical and Political Aspects of Nuclear Power

• An assessment of the acceptability of the risks and benefits of nuclear power must include an assessment of the social, ethical and political implications of its use.

• New and imaginative approaches to inform and involve the public in nuclear decisions which extend well beyond the public hearing process must be developed.

• Timely consultation with affected sectors of society, especially the agricultural community, which will bear a disproportionate share of the risks and inconvenience of all large scale electrical generation, is essential.

• There must be greater and freer public access to information.

• The nuclear industry must continue to become more open to public scrutiny.

• Security measures now in place or contemplated in Ontario for a once-through CANDU programme are not likely to limit our civil liberties.

Nuclear Weapons Proliferation and Plant Security

Proliferation

• There is a demonstrable — albeit complex — relationship between the growing world use of civilian nuclear power and the proliferation of nuclear weapons.

• Ontario Hydro's nuclear power programme does not contribute to nuclear weapons proliferation by non-nuclear-weapons owner countries.

• As the most important producer and user of nuclear technology, Ontario must acknowledge the proliferation problem and perhaps play some, albeit minor role in dealing with it, particularly since exports will be important to the continued well-being of the nuclear manufacturing sector.

• Canada's stringent nuclear export policy should be continued. As long as this country plays a major role in the international nuclear market, Canada must continue to commit resources to the solution of the nuclear weapons proliferation problem in both its technical and political complexity.

Security

• At this stage in Ontario's nuclear programme, the only credible security concern is sabotage against nuclear installations.

• When the new measures currently being undertaken by Ontario Hydro are fully operational, they will give the utility considerable capability to detect and to deter unauthorized intrusion at its nuclear facilities.

• The responsibility for all aspects of security and contingency planning at nuclear plants in Ontario is not clearly defined or understood by all relevant agencies. A comprehensive "crisis management" system involving both security and political authorities capable of making complex and rapid decisions should be created.

The Regulation of Nuclear Power

• Potential difficulties and uncertainty exist with respect to the division of legislative power between the provincial and federal governments concerning regulation of the nuclear fuel cycle, particularly environmental assessment.

• The rationale for a nuclear project should be open to public scrutiny. The Ontario Environmental Assessment Act potentially provides an appropriate basis for public

review of the comparative social and environmental implications of nuclear power development.

- The AECB licensing review should concentrate on important matters relating to safety, security, health and environment. Decisions relating to the use of nuclear power, including ecological, social, economic and political aspects should be the responsibility of the Province of Ontario.

- A close working relationship should continue to exist between the regulator and the regulated. But strong and independent advisory committees, which already play a key role in the Canadian regulatory process, should be continued and expanded.

- The safety of CANDU reactors under extreme conditions should be proved, within limits acceptable to the AECB, by Ontario Hydro. The burden of proof, as in the past, should continue to rest with the proponent.

- The principle of "openness" of the regulatory process is important. Public participation should increasingly be recognized as an essential component of decision-making on nuclear matters. Concomitantly, access to information should be based on "disclosure being the rule and exceptions being strictly limited".

Alternative Supply Technologies

- A primary objective of energy planning should be to develop and have available by the year 2000 a flexible mix of options to meet the diverse needs of Ontario.

- Diversity, flexibility and resiliency should characterize our energy supply systems. Centralized and decentralized, renewable as well as non-renewable systems should be deployed.

- Nuclear energy should no longer receive the major portion of energy research funding.

- There should be much greater expenditure on the development, demonstration and commercialization of energy storage, energy-efficient (co-generation and fluidized bed combustion) and renewable technologies which are compatible with Ontario's energy needs.

- By the year 2000, a minimum of 1500 MW of electric power should be supplied by biomass generation based on the energy forest concept.

- Coal should play a more significant role in our energy mix. Major capital expenditures on a slurry pipeline from Western Canada could provide benefits not only to the utility but also to many Ontario industries.

- Canada should explore opportunities to enter into a joint research programme with the United States on advanced CANDU-thorium cycles in order to optimize both

Canadian and American resources. However, research funding for advanced fuel cycles should be pursued as a low priority, particularly when compared to research and development on nuclear waste disposal.

- Significant benefits would accrue to the people of Canada and Ontario if the research laboratories of Atomic Energy of Canada Limited were converted into one centralized National Energy Laboratory.

Future of Nuclear Power in Ontario

- The maximum number of additional nuclear stations to the year 2000 should be three.
- The reactor size should be standardized at 850 MW.
- One additional site dedicated to nuclear power should be acquired.
- Based on the above programme, on-site interim storage of spent fuel, rather than central interim storage, should be used by Ontario Hydro.
- Based on the above programme, the heavy water output from the third plant at the Bruce nuclear complex will not be needed before the end of the century.
- Governments must recognize that decisions about nuclear power are fundamentally political in the widest sense of the word; they relate to quality of life and quality of the environment; they cannot be left to the utility alone.
- Consciousness of the welfare of future generations should be a central criterion in the evaluation of energy options.

The government and the public can no longer sit back and be relatively uninterested in the generation decisions made by the utility. We must become knowledgeable about the proposed technologies, their environmental, societal and political implications, and their capital and fuel requirements both in the short and long term. We must all enter the debate in a process designed to give political direction to the utility.

INTERIM REPORT ON NUCLEAR POWER IN ONTARIO

Foreword

THE Royal Commission on Electric Power Planning was established by the Government of Ontario in July 1975 in response to public concern, expressed particularly by farmers and environmentalists, about the long-range plans for the development of Ontario Hydro's electric power system.[1] Our mandate is extremely broad (see Annex A). The Commission was directed by Order-in-Council to examine fully the concepts and programme of Ontario Hydro in relation to technical, socioeconomic, and environmental factors for the period from 1983 to 1993 and beyond. The Government requested the Commission to direct its efforts towards establishing a framework for the further development of the electric power system in the best interests of the people of Ontario.

We believe this is a unique opportunity for Ontarians to examine all the implications of an electric power system whose effects may be felt well into the twenty-first century. Indeed the public as well as numerous interest groups recognized this opportunity and came forward to share their concerns and perceptions with us during our Preliminary Public Meetings. These are reflected in our First Report. They continued their active participation in the Information Hearings and most recently in the Debate Stage Hearings.

Many questions have been raised during our two and one-half years of public hearings, but the nuclear power issue — the subject of this Interim Report — has been by far the most controversial. In our Debate Stage Hearings alone, 335 hours have already been devoted to the nuclear question. Nuclear power is praised by some people as the only technology capable of generating adequate electric power by the turn of the century and is strongly criticized by others because of its potentially undesirable impacts. Perhaps much of the public concern stems from the apparent veil of secrecy that has historically surrounded information pertaining to things nuclear. Whatever the reason, the issue is of profound importance to the public.

The appointment by the Ontario Government of a Select Committee to consider the Province's nuclear commitment in its review of Ontario Hydro affairs has provided an appropriate opportunity for the Commission to share the wealth of information we have gathered. In so doing, we hope to facilitate the work of the Select Committee whose task is, we believe, complementary to our own.

Evidence of global interest in the nuclear power debate is reflected by the many international commissions, committees, and task forces that have studied the subject. Several of the most widely quoted are introduced briefly in the Selected Bibliography. We have noted especially the studies and workshops undertaken under the auspices of the World Council of Churches.

Since its inception the Commission has emphasized the centrality of education. During the course of our inquiry a variety of learning environments has been developed — symposia, seminars, workshops, public meetings and hearings. We have emphasized informality and we believe it has paid off. Of particular interest and value was the nuclear seminar held in Toronto in September 1977. The distinguished panellists were Dr. Gordon Edwards, Sir Brian Flowers, Dr. Robert Jervis and Dr. David Rose. Several of the concepts raised

during the seminar are reflected in this Report. We also expect to publish in October 1978 *Our Energy Options*, a series of essays on energy intended for educational institutions; several of the essays relate to nuclear power.[2]

We have consistently advocated a policy of complete openness of information — our Information Centre, open to members of the public, is probably one of the more comprehensive in the energy field in Canada. Only classified information relating to security measures at power stations is not included. Nevertheless, during the public hearings, one of the most frequently expressed concerns related to the lack of available information on operational aspects of nuclear power stations and heavy water plants, including reactor safety studies and reports on accidents and potential accidents and their consequences.

The preparation of this Interim Report has not been easy. Two major problems have predominated: first, the weighting of very diverse points of view; and secondly, the development of an adequate framework in which to portray nuclear power — a single, albeit important, component of a complex total energy system.

We have in this Report provided, for the people and the Government, the Commission's findings and conclusions to date about the future role of nuclear power in the province. Indeed, it is a sincere effort on our part to put you fully into the picture concerning the nuclear story. We have attempted to balance points of view on major issues that are on one hand ethical, socioeconomic, environmental and political and on the other scientific and technical. Further evidence relating to nuclear power will almost certainly be forthcoming during our remaining hearings on the overall design of the electric power system and the decision making and public participation process. Although we do not anticipate that any major new information will emerge to alter our general conclusions on nuclear power, presented herein, only when the full hearing process has run its course and all the evidence has been weighed will we be in a position to formulate specific recommendations.

Throughout the inquiry we have been fortunate to have been assisted by a large number of people (many of whom are named in Annex C) whose participation is gratefully acknowledged. Ontario Hydro has been unstinting in its co-operation and in its efforts to provide us with a vast amount of information, and it is a special pleasure to record our appreciation of the work of Bruce Campbell, counsel for Ontario Hydro, and that of the many panels of expert witnesses whom he presented to us. We express our gratitude to several ministries of the Government of Ontario for providing information and for participating actively in our hearings. We would also like to acknowledge the noteworthy participation of Atomic Energy of Canada Limited, the Atomic Energy Control Board, and Fisheries and Environment Canada.

Many industrial associations, public interest groups, and individuals appeared before us and made valuable contributions in their submissions and during cross-examination. To mention a few, and we do injustice to many: the Canadian Coalition for Nuclear Responsibility (Dr. Gordon Edwards, Ian Connerty), the Canadian Nuclear Association (Alan Wyatt), DynamoGenesis Inc. (Nick Teekman), the Electrical and Electronic Manufacturers Association of Canada (George Vaughan), the Ontario Coalition for Nuclear Responsibility (Ralph Torrie), and a citizen at large, George Meek, who rarely missed a hearing and who participated actively and effectively.

Nor would these acknowledgements be complete without reference to the work of our court reporters, Angus Stonehouse & Company Ltd. It remains a mystery how they were able to cope with frequently very technical evidence that continued for hours on end.

We are, of course, tremendously grateful to the staff of the Commission for their competence, devotion, and cheerfulness. We are very proud of them.

Chapter One

Introduction

ALTHOUGH it seems to have all but disappeared from the consciousness of many Canadians, the 1973 oil crisis was an event of enormous significance whose full implications have yet to be completely understood. The oil embargo imposed by the Organization of Oil Exporting Countries (OPEC) and the subsequent quadrupling of the price of crude oil were triggered by events and problems remote to most Canadians. These events served, however, to illustrate the far-reaching and unpredictable effects of an interdependent world and to underscore a fundamental and inescapable reality: access to plentiful and secure supplies of energy is a critical and potentially fragile cornerstone of contemporary industrial societies that can no longer be taken for granted. Canadians, accustomed to the idea that theirs is a vast land blessed with almost limitless natural resources of all kinds, seem reluctant to accept this reality.

The creation and convenient availability of high-quality energy, such as electricity, is not an end in itself. Rather, energy defined generally is a means, a tool, not only to perform any given end-use (driving a motor or heating water, for example) but ultimately to assist in achieving social, economic, political and even personal goals. Consequently, the broad outlines and well-being of any future society will be significantly influenced by:

- the ends to which the energy produced is ultimately applied
- the sectors of society which benefit from the energy supplied
- the allocation of risks and costs required to capture, process, distribute and consume the energy
- the forms and quantities of energy supplied
- the nature of the technologies required to exploit the energy and
- the institutions which control the energy and the required technical skills.

Quality of Life

The continued availability of abundant energy is clearly essential to the general well-being of modern societies and an important requirement for the maintenance of high living standards. Indeed, the demand for energy by all living entities is predicated on only two factors: growth and maintenance. This is of critical significance in any consideration of society's future needs for energy. In general, the "maintenance" component has received less attention than the "growth" component. But with increasing world population and continuing growth in the utilization of non-renewable energy resources, the reality of increasing energy costs, and the concomitant trend towards energy conservation, more attention will have to be paid to the basic energy requirements necessary to sustain a viable economy and a reasonable standard of living. The issue is admirably stated as follows:

> Our goal for energy, to be realistic, must now be stated in more modest terms, namely a supply of energy that is sufficient for our real needs at equitable prices with acceptable environmental consequences.[1]

Historical evidence suggests that there is a complex relationship between per capita energy use and per capita Gross National Product. There is, however, some evidence to suggest that this relationship can, and perhaps must, be "decoupled".

Some go further and see a direct, causal relationship between energy consumption and quality of life. We cannot accept this argument; indeed, we doubt that a continuation of the postwar exponential growth in demand for energy would, even if it were attainable, result in an exponential increase in human welfare and happiness. Basic human needs and aspirations differ widely from person to person and from culture to culture. And ultimately, all mankind is constrained by the finite limits of earth's fragile biosphere. Quality of life is a function of the availability of, amongst other things: health, educational, cultural and recreational facilities; basic public services such as transportation systems, sanitation facilities and water supplies, and, on a global basis, the mitigation of environmental degradation, hunger, poverty and the threat of war.

Technology will continue to play a significant role in enhancing the quality of life. A few, mostly rural dwellers, have argued that its role should be minimal. However the apartment dweller living on the thirtieth floor of a city building no doubt thinks differently, especially in Ontario, where the majority of the population lives in urban areas. The provision of food alone calls for a high degree of technological sophistication in production, distribution, and marketing. For example, Dr. H.L. Patterson, a representative of the Food Land Steering Committee, described the farmers' need for technology to supply our food requirements:

> Farmers as individuals are more reliant on electricity than the average individual. It is very important that electricity should be supplied as cheaply as possible. The farmer is at present utilizing solar energy, through photosynthesis, but agriculture, as presently established, needs electricity for a whole range of operations.

As this example suggests, energy and especially ubiquitous electricity should be included, albeit in moderation, amongst the basic human needs. However, in an era of exponential resource depletion on a global scale, meeting even basic needs will present mankind with a formidable challenge. The adoption of a "conservation ethic" will play an essential part in meeting this challenge. But in spite of government exhortations, we believe that true energy conservation is practised by comparatively few people. Indeed, most of us appear to be oblivious to the danger signals. The Commission has concluded that heroic measures will probably be necessary to bring home forcefully the urgent need for energy conservation, especially of the non-renewable fossil fuels.

Risk and Uncertainty

All currently available conventional energy systems, regardless of whether they are indigenous to Ontario, have social, ethical, economic, environmental or political costs associated with their deployment. The depletion of oil and gas over the next three decades represents an ethically questionable legacy to any future society whose economic and social well-being may be at stake. Oil pipelines may threaten fragile northern lifestyles and ecology. Hydro dams can fail, drastically alter the landscape and may force local populations to relocate. Coal-fired generating stations emit large quantities of sulphur dioxide and oxides of nitrogen and may significantly alter world climate by adding carbon dioxide to the atmosphere.

We are also aware that a major accident occurring in any nuclear power plant, or facility, could have significant environmental and political implications. In addition, radioactive wastes, both uranium mill tailings and reactor spent fuel, must be isolated from man's environment for very long periods of time. No universally acceptable methods of disposing of these wastes have yet been devised. Moreover, as these wastes accumulate, in the absence of socially and technically acceptable disposal solutions, they will constitute a growing threat to the local and even the earth's ecology. Global reliance on nuclear power will result in the rapidly increasing production of "fissionable isotopes", most notably plutonium-239, which, although a valuable energy source in its own right, is both a highly toxic substance and can be used in the manufacture of nuclear weapons.[2] This reliance may increase the probability of nuclear weapons proliferation. The international monitoring and control of this technology, admittedly a highly complex problem, should become a world objective. The achievement of this goal promises, however, to be elusive. An associated concern is the possiblity of the illicit use of nuclear materials for

malevolent purposes by criminal or terrorist groups or of terrorist attacks on nuclear power facilities.

Paradoxically, living with risks is what makes life possible. Further, the more uncertainty the greater the risks. Throughout the history of life on earth, there have been several major transitions in lifestyles. For example, from hunting to agrarian society; from agrarian to industrial society; and currently from industrial to post-industrial society. These transitions have been characterized by marked social unrest and uncertainty. Indeed, the philosopher Alfred North Whitehead once remarked that one manifestation of wisdom was to recognize that major changes in society and culture almost destroy us. As the degree of uncertainty increases so does the need to "invent the future" and all true invention necessitates risk-taking. Indeed, risk-taking is almost taken for granted in modern society. We routinely risk our lives in automobiles, aircraft, and even while participating in sports. Certainly, the risks and the benefits associated with nuclear power have emerged as central issues during our public hearings.

The acceptability and perception of risk by individuals or society are complex questions predicated essentially on value judgements. It is abundantly clear, however, that most people accept voluntary risks much more readily than they accept involuntary risks. Increasingly, benefit-risk analysis is becoming an important component of technology assessment.

Moreover, we have not only to weigh the risks and benefits of energy technologies to present generations but also to consider the potential risks and benefits to future generations.[3] The future risks to be taken into account relate to such things as potential genetic damage from radiation, bequeathing to future generations stocks of radioactive material, and contamination of the environment by the burning of fossil fuels, emissions from automobiles and proliferation of deadly chemicals. Future generations could be put to significant risk if this generation continues to denude the earth of its limited non-renewable resources and perhaps even changes the weather patterns as a result of accumulating emissions of carbon dioxide. Nor should we dismiss lightly the risk of becoming overly reliant on comparatively untried energy technologies.

All likely long-range energy supply options which might be available in the period after 2000, whether they are nuclear, fossil or renewable (solar energy in all its forms), are characterized above all else by uncertainty at this time. To complicate matters further, it is extremely difficult to predict energy demand beyond the short to medium term with any degree of confidence because complex assumptions must be made about such factors as demographic trends, economic growth rates and lifestyles. It is equally difficult to determine in advance the effect of relative price increases and conservation/efficiency programmes on future energy demand patterns.

Therefore, as the epoch of cheap, seemingly inexhaustible energy draws to a close, the value of having energy in abundance will increasingly have to be weighed against a complex and uncertain new range of costs which will be incurred in making it available in the quantities, forms, and places to which we have become accustomed. This is the dilemma and the challenge which we face as we attempt to plan our energy future. There will be no panaceas. As fossil fuels escalate in price and approach depletion over the next 25 years, time itself will increasingly become a scarce resource — it is not coincidental that we have chosen "A Race Against Time" as the subtitle of this Report. Given the realities of technological and political lead times required to put new energy systems in place (the CANDU technology required 25 years to develop and make commercially available), the price of misjudgement will, at best, be increased costs, and at worst, the risk of not having sufficient energy at some point in the future.

Future Problems

It has been said that: "One of the chief frustrations of our times is a surplus of simple solutions combined with an enormous shortage of simple problems."[4] After two and a half years of public hearings and debates we can attest, most fervently, to the accuracy of this assessment of contemporary problems. The decisions ahead, especially in the energy field, will inevitably be hard decisions. They will relate to, and indeed determine, the

shape of our future society; these in turn will be predicated on how effectively man protects the earth's ecosystem (which includes himself and his foodlands), his cultures, his living standards, and not least his dwindling non-renewable resources.

The choice, based on socioeconomic, environmental, and technical criteria of the most appropriate technologies to deal with specific situations will underlie many of the decisions. Technologies such as advanced nuclear fuel cycles, for example, will have to be assessed to ensure that the potential benefits of the technology outweigh the potential risks of the technology and its side effects. As we have pointed out on numerous occasions, the citizens of the province should have the opportunity to participate in this assessment because their future, and the future of their children and grandchildren will be profoundly affected by the ultimate decisions, which will be taken by the Government of Ontario, relating to the province's future electric power system. It is important also that the critical and evaluative capacity of individuals and groups who can contribute to policy formulation should be strengthened. In this regard, the work of many public interest groups in Ontario, and the work of scholarly and scientific societies should be encouraged and, where necessary, financed. Citizens' interest groups and the scientific and technical community should have equal access to adequate and readily understandable information. As indicated by the World Council of Churches:

> We are justified in demanding the most accurate possible knowledge of the advantages, risks and hazards of nuclear power and also of the alternatives.[5]

There is a vast amount of scientific information on nuclear power, civilian and military, available in the literature.[6] In particular, the contributions of Atomic Energy of Canada Limited (AECL) to this literature are impressive, but the majority of them are completely unintelligible to the lay public; they have been written essentially for the world community of nuclear specialists.[7]

Regrettably, regardless of the publications for public consumption of several public interest groups (notably Energy Probe and the Ontario Coalition for Nuclear Reponsibility), of Ontario Hydro, of the Canadian Nuclear Association, of numerous foreign commissions, committees and task forces (most of them eminently suitable for reading by laymen),[8] and of popular scientific writers, the majority of the "informed public" remains comparatively illiterate in matters that relate to nuclear energy and indeed to energy in general.

In a real sense the central task of the Commission is one of technology assessment — the assessment of the basic planning concepts that underpin Ontario's electric power system, of which the nuclear power programme is an important component.

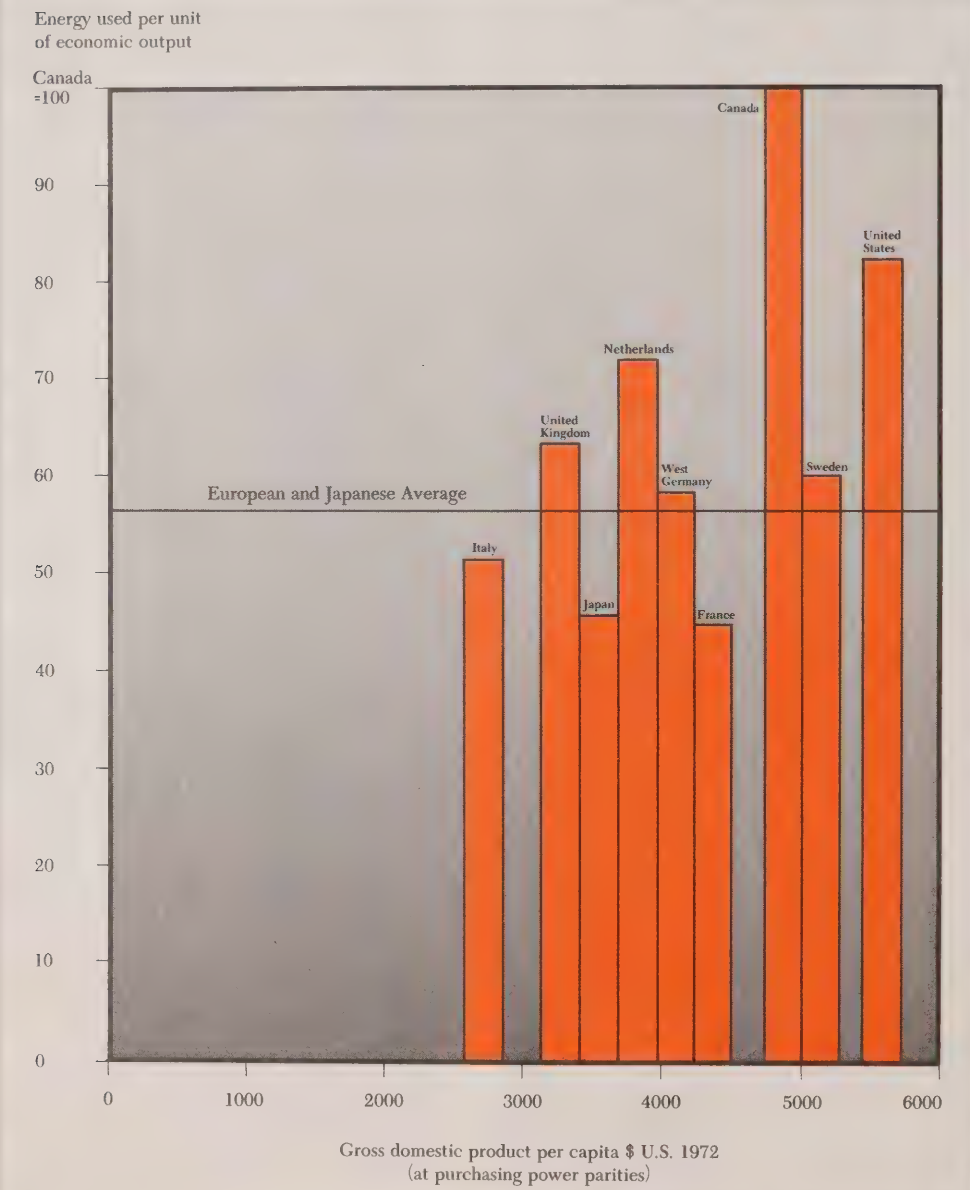
We have recognized since the early stages of the inquiry that no single component of the total system, such as nuclear power, however important, can be treated in isolation. Analogously, the single lines of a poem, however dramatic or poignant, cannot convey the meaning of the whole when read independently. Nuclear power is a key issue, but it is not the only issue. For example, hydraulic power and the generating technologies based on the fossil fuels will continue to play a significant part in Ontario's electric power system. As well, we anticipate that various alternative energy sources will become increasingly important.

In this Report we seek to portray nuclear power in this larger context. The basic questions we address are the familiar ones. How much energy and electric power are required? How should it be generated? What are the components of a nuclear fuel cycle? What are the health, environmental and safety implications? What are the comparative economics of nuclear power and how can the programme be financed? What are the prospects for the Canadian nuclear components industry? How adequate are uranium supplies? What are the socioeconomic, political and ethical implications? How adequate is the regulatory process governing the nuclear fuel cycle? What is the future role for nuclear power?

A vision of the future based on the notion of a "sustainable" society powered by environmentally benign, abundant and affordable technologies would find few critics. The debate is, of course, centred on the strategies required to bring such a society into being while reducing exponential

growth without generating economic disaster during the transitional period to approximately the year 2000. In light of the many uncertainties over the medium to long term which will likely characterize both the demand and supply parameters of the energy equation, we have concluded that energy and electricity planning in Ontario should seek to maximize flexibility during the transitional period. It should be a primary objective of energy planning to develop and have available by the year 2000 a flexible mix of options to meet the diverse needs and to exploit the varied capabilities of Ontario. The energy commitments which are undertaken at the turn of the century should be made because they are the best thing rather than the only thing to do.

Figure 2.1 International Comparison of Energy Use



SOURCE Based on Joel Darmstadter, et al., *How Industrial Societies Use Energy: A Comparative Analysis* (Baltimore: Johns Hopkins University Press, 1977).

Chapter Two

The Demand for Electricity

We believe that the issue of uppermost importance remains that of critical examination of the demand projections which have been made for electric power. — *Sierra Club of Ontario*

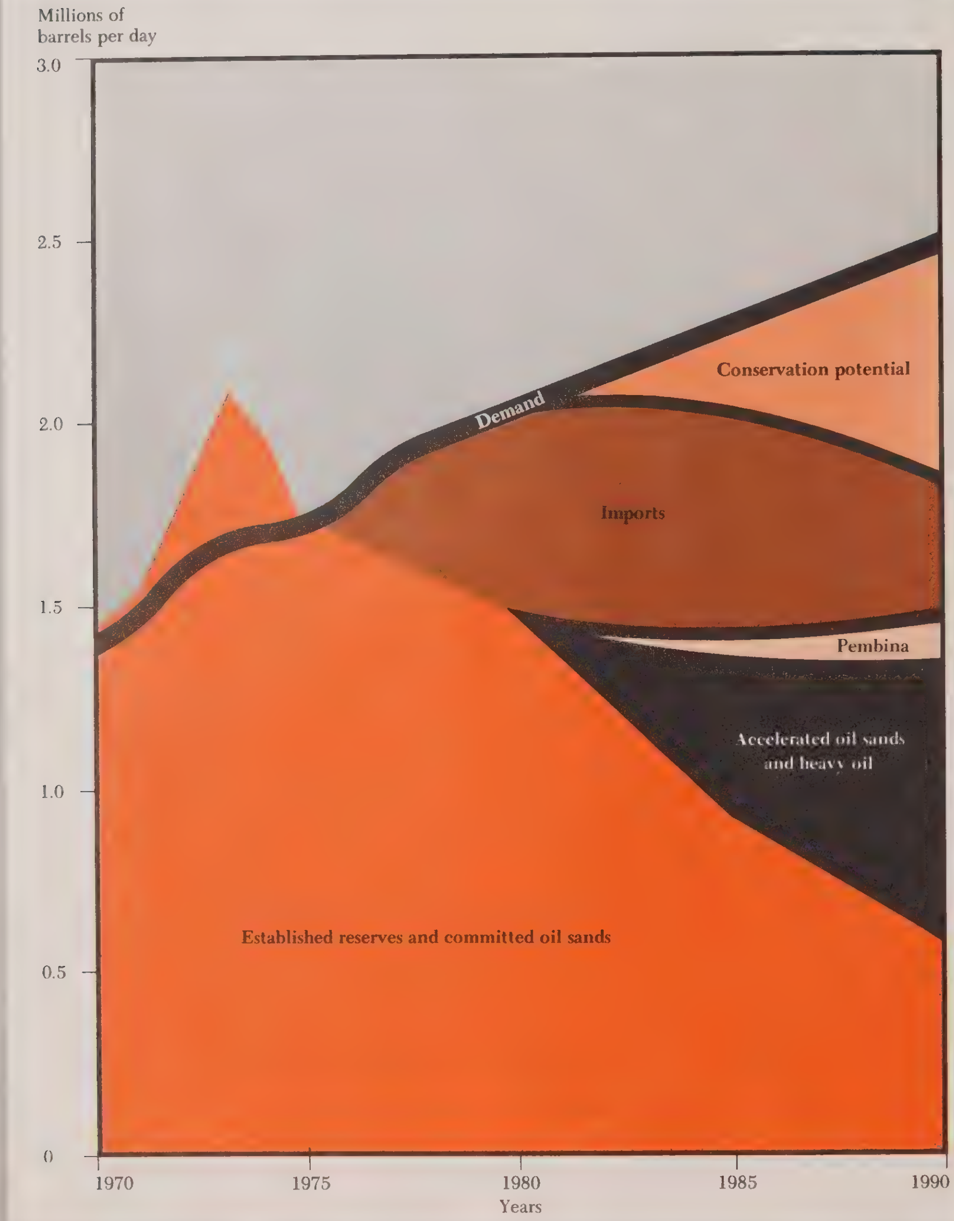
DURING the public hearings of the Commission the issue of the future demand for electric power[1] in the province has been raised on many occasions. Probably the reason is that the public recognizes, as do we, that the demand for electricity is closely related to the future growth of Ontario — growth of population, growth in food requirements, growth of industry to provide jobs for an increasing labour force, and by no means least, growth of social institutions, especially in the health, education and public service sectors. Certainly in the past fifty years the development of the electric power system of the province has played a key role in the economy; electricity can be readily adapted to the demands of technological society and gives rise, in itself, to new technology and to cultural change. But there is a sound basis for the concerns relating to the future demand for electricity.

Canada consumes more energy in proportion to economic output than any other western country (Figure 2-1). Furthermore, on a per capita basis, our consumption ranks second only to that of the United States. Ontario, with a population of 8.4 million, representing about 36 per cent of the nation's population, accounts for roughly the same proportion of its energy consumption. Beginning with the implications of the world's declining oil resources, and concomitant price increases, we outline below the major factors which will determine, in large measure, the future demand for electricity in Ontario.

In common with most western countries, Canada and Ontario depend on oil as their major source of energy. Although most of Ontario's oil comes from western Canadian sources, these supplies are being depleted; as well, federal government policy is to increase the price of domestic oil to international levels. It has been estimated that if the share of oil consumed can be reduced from the present level of 46 per cent of all energy used in Canada to about 30 per cent by the year 2000, then western Canadian supplies will probably meet most Canadian requirements, assuming the proposed tar sands oil expansion meets expectations and can offset the decline in supply from conventional western sedimentary basin reserves.[2]

But no matter what corrective action is taken, it is probable that Canada will have an oil gap in the medium term. Figure 2-2 shows current projections of Energy, Mines and Resources Canada of oil availability and the size of the oil gap through 1990. These are, however, premised on fairly optimistic assumptions on the supply side, and on the success of both voluntary and mandatory conservation measures operating on the demand side. Even so, the import bill will create a major energy balance-of-payments deficit unless significant quantities of Alberta natural gas, of which there is at present a surplus, are sold to the United States.[3] According to a senior energy advisor of Energy, Mines and Resources Canada, "with no turnaround in the energy supply-demand situation, Canada would be facing a trade deficit in its oil account alone of $7 to $8 billion a year in the latter half of the next decade".[4] Beyond the year 2000 our domestic oil and natural gas supply position will depend upon the economics of natural gas extraction from "tight" western Canadian strata and frontier regions, and oil extraction from tar sands and shales. At present the National Energy Board is conducting hearings into oil availability.

Figure 2.2 Canadian Oil Demand and Availability 1970-1990



SOURCE Energy, Mines and Resources, Canada, February 1978, "High Price Scenario".

Together with growth in the population and economy of Ontario, the key determinants of the future demand for electricity will be the measures adopted to fill the oil gap. These will include some combination of conservation, substitution of other energy forms, and improved energy efficiency; for example, through the co-generation of electric and heat energy. We deal briefly with each of these below.

Energy and Population

The rate of growth of total demand for energy is highly sensitive to demographic variables. Indeed, the growth rate[5] is approximately the sum of the population growth rate and the rate of growth of per capita energy consumption.[6] Ontario Hydro has stated that, "in a very general way", of the historic growth in electrical demand, about 6.7 per cent per annum, slightly more than 2 per cent is due to population increase and the remaining 4.7 per cent is due to increases in per capita consumption. Of the latter, about 3 per cent is "normal" increase (presumably, increases in productivity) and 1.7 per cent is due to conversions to electricity.

The relationship between future demand for electricity in Ontario and the growth of the province's population and economy is complex. This is essentially because such key factors as Gross Provincial Product, inter-energy substitution, and the impact of energy conservation interact in a complex way. Some of the scenarios, introduced subsequently, illustrate the complexity of these relationships.

Ontario's population growth is a function of fertility rates and net migration into the province. These are difficult variables to predict. Table 2-1 shows the effects on population growth of different combinations of these factors. It is noteworthy that changes in expected fertility rates can only have comparatively small effects to the end of the century. But the population growth rate is highly sensitive to immigration, and if Canada's economic growth rate improves, resumption of the high immigration rates of the 1960s cannot be ruled out.

From 1958 to 1973 Ontario's population grew at 2.1 per cent per annum; this should be contrasted with the present official government forecast of 1.4 per cent average to 2001, and an unpublished later estimate of 1.2 per cent. Some demographers believe population will increase even more slowly. Indeed, a study undertaken for the Commission forecasts a population increase of 0.4 percentage points lower than the "official" forecast.[7] If, for example, Ontario Hydro's forecast load growth of 5.3 per cent to 2001 is predicated on the official population forecast, then a reduction of 0.4 percentage points in population growth — equivalent to approximately 1 million fewer Ontarians in 2001 — would reduce the required additional electric capacity by 12 per cent, or the equivalent of almost three Pickering A power stations.

The scenarios presented later are based on 1.2 per cent as "medium" population growth, and 0.9 per cent and 1.5 per cent as "low" and "high" growth respectively.

Energy and Economic Growth

To exemplify the relationship between economic activity and the demand for electricity, we have singled out five basic components of the problem. First, the energy needs per unit of economic output; secondly, the reduction of these needs through conservation; thirdly, the possible saturation of the consumer market; fourthly, changing patterns in industry; fifthly, the substitution of other energy forms, including electricity, for oil and gas.

As we pointed out earlier, historically, Ontario's steady economic and industrial growth have been accompanied and facilitated by a concomitant growth in energy use (Figure 2-3). However, in the longer term, as energy supply and utilization technologies have changed, there have been alternating periods of falling and rising energy consumption relative to economic growth. Paul W. McCracken, former Chairman of the President of the United States' Council of Economic Advisors, has been quoted as saying that

> the striking thing about the relationship between the rate of growth in output and the rate of increase in energy consumed is not that it obviously exists, but that it is so variable. This suggests that we cannot be certain what a

Table 2.1 Effect of Fertility and Migration on Population, Ontario, 1975-2001

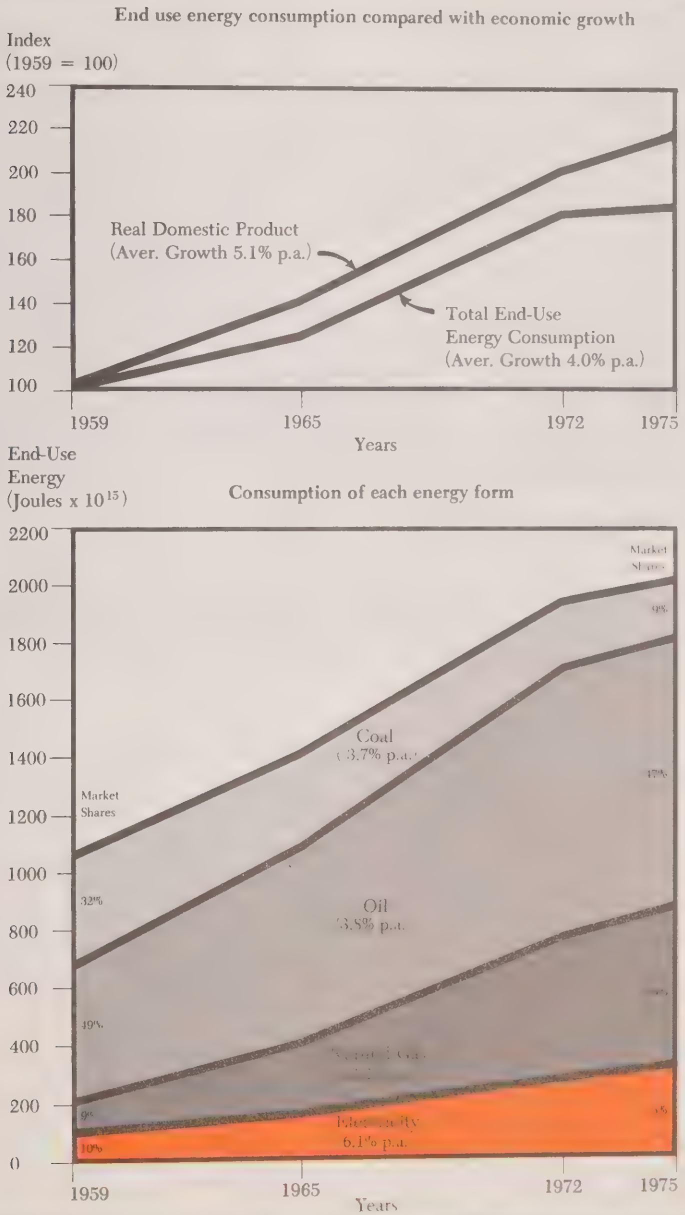
Fertility	Net migration into Ontario (Thousands)	Average annual rate of population growth (per cent)	Population in 2001 (Millions)
Low	25,000 50,000 75,000	0.9 1.3 1.6	10.3 11.2 12.2
Medium	25,000 50,000 75,000	1.1 1.4 1.7	10.7 11.6[1] 12.6
High	70,000	2.1[2]	13.7

1 Ontario Government Official Projection.

2 Actual growth rate 1958-1973.

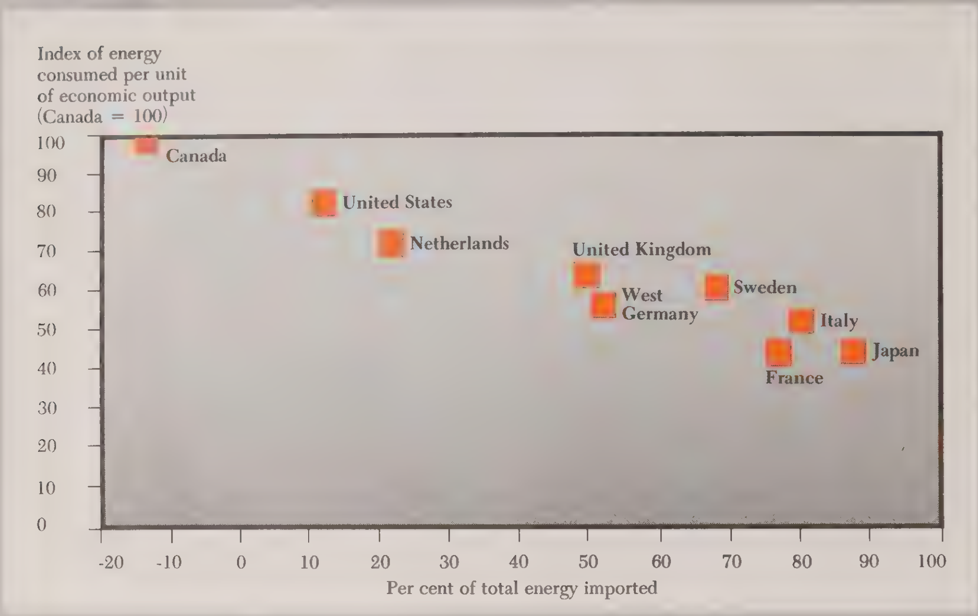
SOURCE Economic Analysis Branch, Ontario Ministry of Treasury, Economics and Intergovernmental Affairs, 1975.

Figure 2.3 Ontario Energy Consumption and Economic Growth 1959-1975



SOURCES Energy Data from Statistics Canada 57 207.
Economic Data from Ontario Ministry of Treasury, Economic and Intergovernmental Affairs and Canadian Statistical Review, August 1977.

Figure 2.4 Effect of Import Dependence on Energy Use



SOURCE Based on Joel Darmstadter, et al., *How Industrial Societies Use Energy: A Comparative Analysis* (Baltimore: Johns Hopkins University Press, 1977.)

change in energy availability will mean for economic activity.

Referring again to Figure 2-1, it is noteworthy that we Canadians, at present, require about 75 per cent more energy, per unit of output, than several other western industrial nations. The reasons for this apparently profligate use of energy are the immense size of the country, its comparatively severe climate and the preponderance of high energy-intensive industries, such as the forest and mining industries. But there is another reason: nations like Canada, with abundant and cheap energy supplies and virtual energy self-sufficiency, have tended, historically, to be more prodigal in energy use. This is strikingly illustrated in Figure 2-4. The implication is that as our energy prices approach world prices, and as conservation measures take effect, our "energy-intensity" — the amount of energy we need to produce a unit of output — will tend to approach that of other countries. In consequence we anticipate a gradual decoupling of energy use and economic growth that will last at least until we have achieved a higher degree of energy efficiency.[8]

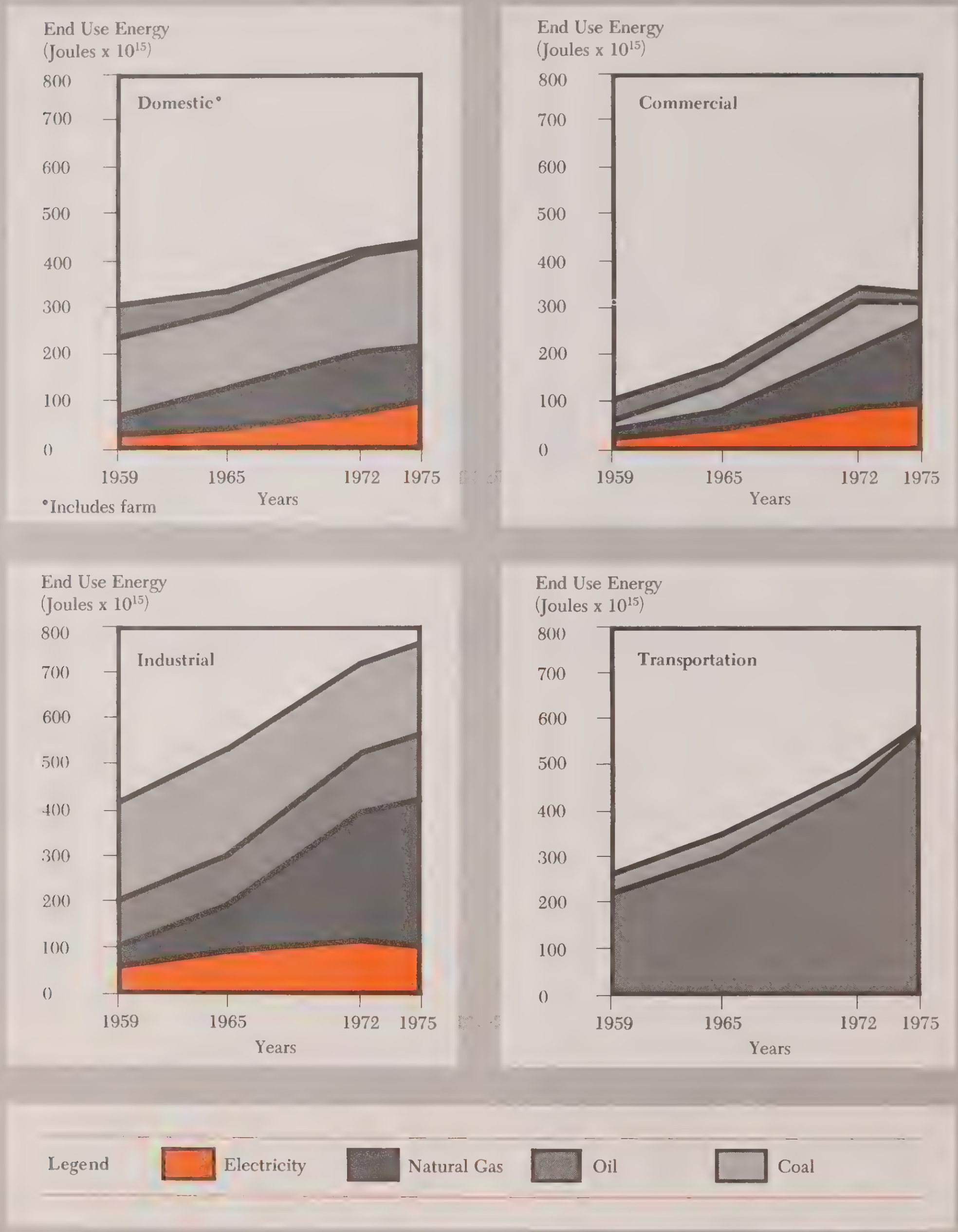
Energy conservation, and all that it implies, is clearly a central factor in any assessment of the future demand for electricity. Fortunately, the conservation ethic appears to be acceptable, at least in principle, to a broad cross-section of the people of the province, to their governments — federal, provincial and municipal — and in the main, to the utilities that serve them.[9] Quite simply, conservation implies the wise and careful use of a resource. How much energy can be saved by comparatively simple means, without much, if any, change in lifestyle? Perhaps much more than we think. The two largest opportunities for energy conservation in Canada and Ontario, in the midterm, are space heating and automobile mileage performance. It is important to realize that these and other essentially non-electric conservation measures may have a major effect on future electrical demand since they reduce the need to substitute electricity for oil and gas.

Interestingly, the practice, in the broadest sense, of conservation could provide a boost to the economy of the province in the replacement of energy-intensive materials machines and processes by more efficient systems.[10] Furthermore, there is a burgeoning interest in such "conservation technologies" as solar energy and the "heat pump".[11] (Under the heading "The Non-Nuclear Options for Ontario", some of the conservation technologies are described in Annex E.) However, it cannot be over-emphasized that the so-called alternative technologies are not ready-made energy panaceas. In one way or another, each of them requires the investment of both capital and energy. To save energy in the long run, we may, and probably will, have to expend more energy, as well as capital, over the short run. But we can be certain that such investments will prove increasingly profitable as energy prices rise. Slowly, but inexorably, the practice of conservation and the introduction of the "conservation technologies" will reduce the future demand for both total energy and electricity. This is well illustrated in the tentative energy demand scenarios presented later in this chapter.

Ultimately energy consumption will depend on other fundamental questions, such as the effects on economic growth of possible saturation of consumer markets, and changing patterns of industry. Demand may already be moderating for such energy-intensive amenities as food, space heating, and transportation.[12] We have noted, in particular, that there is some evidence of a degree of "saturation" in the electrical appliance market. Factors which militate against saturation include increasing obsolescence levels of consumer goods, the need to divert productive capacity to meet environmental and conservation requirements, and the mining of increasingly hard to extract mineral and fuel resources. We are studying potential economic saturation with the help of Dr. B.C. McInnis of Statistics Canada, using the Department's long term simulation model.

Almost 40 per cent of Ontario's industrial electrical energy demand is accounted for by three large and energy-intensive industries — pulp and paper, industrial chemicals, and iron and steel. Moreover, the depletion of mineral resources may call for increasing energy needs in the mining industry, the fourth major consumer. But if the current drive towards less energy-intensive secondary industry is successful there will inevitably be a reduction in industrial energy needs. For example,

Figure 2.5 Ontario's Sectoral Energy Use, 1959-1975



SOURCES Energy Data from Statistics Canada 57-207. Economic Data from Ontario Minstry of Treasury, Economics and Intergovernmental Affairs and Canadian Statistical Review, August 1977.

automobile manufacturing requires only about one-twelfth as much energy per dollar of value added as pulp and paper. Employment and balance-of-payments objectives may stimulate this drive, but the effect will inevitably be to moderate energy requirements. Other examples in Ontario are the communications, information processing, and electronics industries. Not only do these industries tend to be labour intensive, and low energy users but, additionally, they are energy savers through the manufacture of computer-based energy management systems. Such systems are becoming increasingly important in medium- and large-scale energy conservation programmes. Just as "load management" is an important requirement in an electric power system, so is the energy management system in industry, because of escalating energy costs. Furthermore, we must look forward increasingly to trading off energy (for example in transportation) for communication. Areas such as these provide opportunities for imagination and initiative as well as government encouragement and stimulation.

We next pose the question: What substitutes for oil (and, to a lesser extent, certainly over the time period of concern to us, for natural gas) are or will become available? The changing mix and corresponding growth rates of the major forms of "end-use" energy in Ontario for the period 1959 to 1975 are shown in Figure 2-3, and for energy use by sector in Figure 2-5. Over the sixteen year period, oil and natural gas increased their share of the "end-use" market from 57 to 76 per cent, while electricity's share increased from about 10 per cent to almost 15 per cent. Clearly the problem of finding suitable substitutes for oil and natural gas will not be easy.

In recent years, there has been a huge increase in energy consumption, and concomitantly in energy waste, in the commercial sector, a major increase in the transportation sector (which accounts for most of the high rate of increase of oil consumption in Ontario), and a gradual increase in energy consumption in both the industrial and domestic sectors.

Any consideration of fuel or energy substitution must take into account the basic end-use categories, together with their respective total energy and electricity requirements, as shown in Table 2-2.[13] Three end-use categories — space heating, water heating, and industrial process heat — consumed about 57 per cent of all Ontario's end-use energy in 1974. This need was met largely by oil and natural gas; like electricity, both are high-quality energy sources. We have no reason to believe that the situation in 1978 differs appreciably from that in 1974.

The future demand for electricity will depend, very markedly, on the extent to which it is used for space and water heating, and for industrial process heat. It has been argued that such comparatively low-temperature energy uses should be supplied, as far as possible, by renewable, or low-quality, heat sources. Solar energy and district heating are mentioned most frequently as the preferred sources. However, it is important to bear in mind that, although thermodynamically optimal, such energy sources may not be economically, or indeed environmentally, acceptable.[14] Accordingly, although renewable energy sources are admirably suited for some applications, they are clearly quite unsuited for others. For example, solar energy is appropriate for space and water heating, but is not well suited to generating industrial process heat where the required temperatures exceed about 100°C.

At present about 10 per cent of Ontario's homes are electrically heated. However, the proportion has been increasing recently; over 30 per cent of newly constructed dwellings are electrically heated. Because of the seasonal nature of the electric space heating load in Ontario, it is highly probable that the present electricity rates are below the true cost to Ontario Hydro of supplying this load. More appropriate pricing of electricity for space heating purposes might have the desirable effect of increasing the competitiveness of solar energy and district heating.

Ontario Hydro's Load Forecast

Every spring, Ontario Hydro issues a load forecast as the basis for planning expansion of the electric production and delivery systems. Since 1922, peak electricity demand has followed an average growth trend of 6.8 per cent per annum. After

Table 2.2 Ontario Energy Consumption by End-Use Catagories, 1974

End use category	Share of total energy consumption (per cent)	Share of total electricity consumption (Per cent)	Electricity consumption as a proportion of total energy consumption
Residential[1]			
Space heating	14.0	5.8	6
Water heating	3.0	8.6	41
Air conditioning	0.1	0.3	100
Other appliances	2.1	14.1	96
Farm equipment	2.5	—	—
Total	21.6	28.8	19
Commercial			
Space Heating	9.3	2.1	3
Water heating	1.2	1.4	16
Air conditioning	1.3	8.9	100
Other	3.5	18.5	77
Total	15.3	30.9	29
Transportation	25.8	—	—
Industry			
Process steam	17.2	—	—
Direct heat	11.8	2.8	3
Electric drive	4.4	30.7	100
Electrolytic processes	0.4	2.8	100
Lighting	0.6	4.1	100
Other	2.9	—	—
Total	37.3	40.3	16
Total Ontario	100.0	100.0	14
Major Heat Items			
Space	23.3	7.9	5
Water	4.2	9.9	34
Industrial process	29.0	2.8	1
Total	56.5	20.6	5

[1] Includes farm consumption.

SOURCE Approximate values estimated RCEPP.

1969, however, it decreased to 5.2 per cent. Nevertheless, for a variety of reasons, load forecasts remained above 7 per cent until 1976. The 1977 and 1978 load forecasts were predicated on growth rates, to the year 1985, of 6.4 per cent and 5.5 per cent, respectively. Accordingly, the addition to peak load expected between 1975 and 1985 is 35 per cent (i.e. 4940 MW) lower than was predicted in 1976. Since Ontario Hydro attempts to maintain a reserve capacity margin of approximately 25 per cent over peak load, this reduced load forecast implies a corresponding capacity reduction of 6200 MW; this is the equivalent of more than three Pickering A stations.

The utility's system expansion programme corresponding to the 1977 load forecast would result in a projected capacity for the east system of about 3000 MW over that called for under the new load forecast to maintain preferred levels of reliability. This "surplus" was reduced to about 1900 MW by the cancellation, announced by the provincial Minister of Energy on April 17, 1978, of construction of two oil-fired units at the Wesleyville generating station. The effect of changing forecast growth rates is exponential. It can be dramatic. The 1977 peak demand in Ontario was 15,700 MW. A 6.2 per cent average annual growth rate (Ontario Hydro's 1977 forecast) would result in a peak demand in 2007 of 95,400 MW, whereas a 5.1 per cent growth rate (1978 forecast) would result in a 2007 peak demand of only 69,800 MW.

In addition to the Ontario Hydro load forecasts, several projections of demand for electric power have been submitted to the Commission. We mention just two. The Ontario Ministry of Treasury, Economics and Intergovernmental Affairs estimates a potential range of increase in electricity demand to 1995 of 3½ to 5½ per cent per annum. Dr. R.J. Uffen, Dean of Applied Sciences, Queen's University, suggests that the most probable among a number of scenarios is one involving a linear addition to demand at the rate of 1,000 MW annually. While it produces the same additional demand by 1985 as Ontario Hydro's latest load forecast, Dr. Uffen's scenario implies an average of 4 per cent annual growth to 2000 in contrast with Ontario Hydro's 5.3 per cent average growth to the same year.

Some Tentative Electrical Demand Scenarios

During our inquiry we had the benefit of productive discussions with energy analysts and policy advisers of Energy, Mines and Resources Canada, the National Energy Board and the Ontario Ministries of Energy, and Treasury, Economics and Intergovernmental Affairs. We are grateful for the unstinting help of these individuals, too numerous to mention here, in assisting us to understand the intricacies of electrical growth. We also thank the Canadian Electrical Association who included us in a seminar to discuss new forms of electrical energy forecasting. These discussions, together with the considerable amount of data we assembled during our hearings, have made possible the development by the Commission of a simple model to examine some key interrelationships. For the purpose of this report we present some basic assumptions and conclusions. In particular, we have used the model to exemplify the central importance of conservation in our energy future.

The model presents electricity requirements as a function of the variables introduced earlier in this chapter: population growth; productivity growth; degree of conservation; availability of oil and natural gas; and the substitution of coal for oil and natural gas in the industrial process heat market and the penetration of renewable energy forms.[15]

It is convenient to introduce "degree of conservation achieved" in terms of an energy growth coefficient. This is defined as total energy growth rate divided by the economic growth rate (real domestic product). The greater the degree of conservation achieved the smaller the energy growth coefficient. We have designated the conservation levels as A, B, C, D. These are based on historical information, as well as conservation projections. The numerical values and basis for estimation associated with each level are as follows:

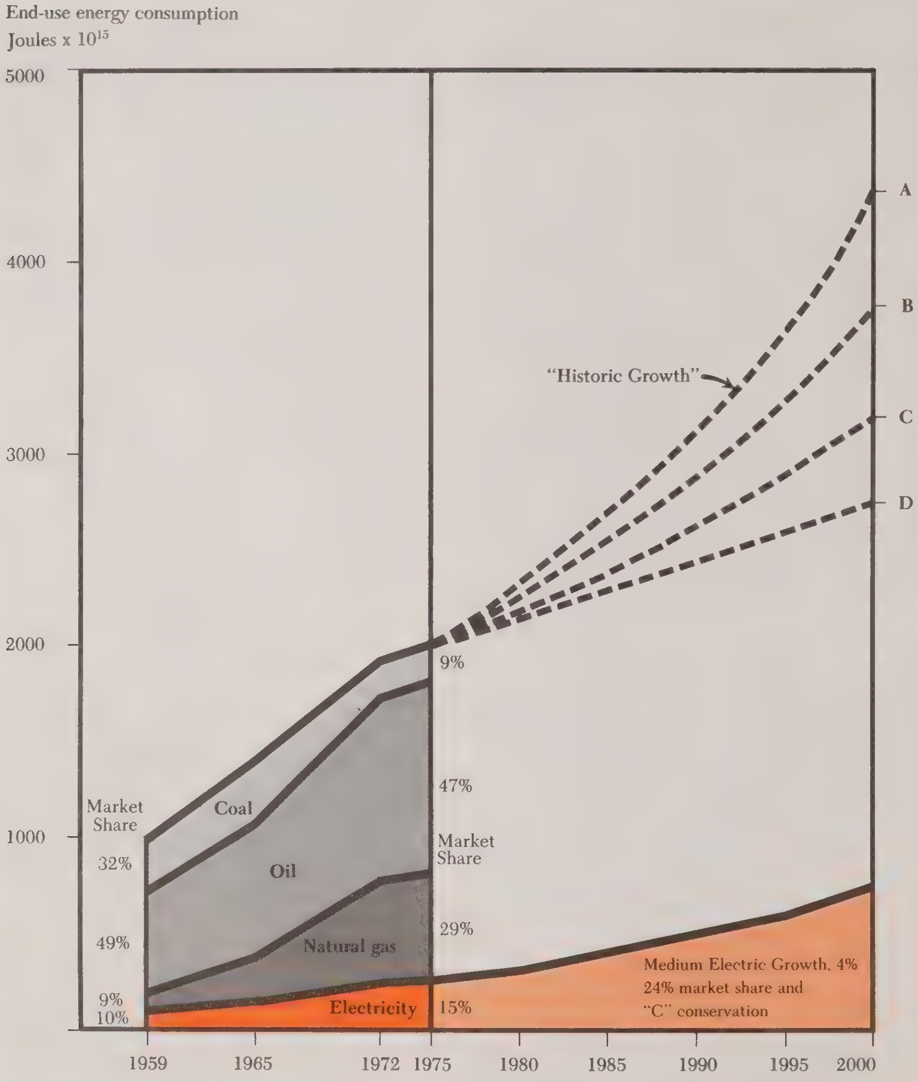
A — No conservation: the historical relationship between energy and economic growth in Ontario (1959-1972) — 0.81

B — Low conservation: the post-OPEC period of price-induced conservation[16] — 0.64

C — Medium conservation: partial attainment of the potential indicated under Level D — 0.48

D — High conservation: the potential indicated by

Figure 2.6 Ontario Total End-Use Energy Requirements, 1975-2000



A No conservation: growth rate 3.2 per cent
B Low Conservation: growth rate 2.6 per cent
C Medium conservation: growth rate 1.9 per cent
D High conservation: growth rate 1.2 per cent

1 Assuming medium economic growth, 4.0%.
SOURCE Projections by RCEPP.

Energy, Mines and Resources Canada for the period to 1990[17] — 0.31.

Figure 2-6 shows the striking impact on total Ontario end-use[18] energy growth to the year 2000 of the above four conservation levels, assuming medium economic growth of 4 per cent.[19] (Medium economic growth results from medium population growth and medium productivity growth.) We present here three scenarios: "high" (6 per cent), "medium" (4 per cent), and "low" (2 per cent) annual growth in demand for electrical energy for the period 1975 to 2000. Ontario Hydro's most recent forecast is 5.3 per cent over the same interval. Each of the three growth rates is within the bounds of possibility. Each can be achieved through many different combinations of our key variables. For example, if conservation is only at the low level, then with medium population and productivity growth, severely restricted availability of oil and gas, and only slight penetration of renewables, high (6 per cent) electrical growth will be required, despite a high use of coal. But even with conservation at the medium level, this high level of electrical growth will be required under the following conditions: the immigration rate reverts to its 1960s level, Canada decides to reserve some natural gas for use after 2000, or to export it, if international prices become very high, and the expansion of coal into industry is merely moderate. Indeed, such a high electrical growth rate coupled with high conservation has been projected by a major study undertaken in the United States.[20] Similarly the low (2 per cent) electrical growth rate is possible if natural gas and oil exhibit a moderate but not unreasonable rate of growth, either with low economic growth allied with medium conservation, or medium economic growth allied with high conservation.

Two important conclusions are readily derived from our model. First, energy conservation is of profound significance and must be pursued with vigour, and secondly, until uncertainties relating to the central variables we have identified are at least partially resolved, it is extremely difficult to forecast, with any degree of reliability, future demand for electric power.

On the basis of present incomplete knowledge, our "interim conclusion" is that the most probable electrical growth rate to 2000 is in the 4.0 per cent range. While stressing the credibility of the 6 per cent growth scenario, we believe it reflects too little conservation, too little oil or gas, and too high a rate of productivity growth. It may also imply too fast a rate, in practical terms, of electricity substitution in space heating or industrial process heating. Indeed, much more in-depth study of the question of the true cost of electricity in space heating is required before its large-scale adoption can be assumed. Significant too is the conclusion of a study carried out for the Commission based on the Ontario Ministry of Energy's demand model, which suggests that 6 per cent electrical growth would be difficult to achieve.[21]

The 2 per cent electrical growth rate is also credible; it is supported by the consultants' study just referred to.[22] Further, there are factors which tend to reduce the rate of growth of energy demand on Ontario Hydro's system that we have ignored in our simple model. These include increased future use of industrial self-generation and co-generation, and the use of thermal generating station waste heat for space heating and industrial process heat. Improved load management, although it does not change the energy growth rate, does lower the rate of growth of peak demand and hence the total system capacity requirements.

However, two main factors militate against the 2 per cent electrical growth rate: first, a possible relatively rapid growth of "necessarily electric" uses, especially industrial motor drives, may occur.[23] This factor is inadequately treated in our simple model and in the present version of the Ontario Ministry of Energy model. Secondly, the anticipated world-wide tightening of oil and gas availability starting about the mid 1980s, with consequent increases in international prices, could encourage increasing use of electricity.

There is clearly a need, at both federal and provincial levels, to develop a total energy planning framework. The so-called LEAP (Long-range Energy Assessment Program) study of Energy, Mines and Resources Canada is a beginning in this direction, as is the Ontario Ministry of Energy's Supply and Demand for Energy study. Such programmes should be encouraged.

Chapter Three

The Supply of Electric Power—Planning for 2000

HAVING determined a forecast of peak demand, an electric utility then proceeds to establish how much new capacity is required, when it is needed, what types are most desirable and where the new plants should be located. This is known as the system planning process. Twenty-year planning is now recognized as necessary by Ontario Hydro. The planning horizons are long because of the time required for public participation, government approvals, site acquisition, design, construction and commissioning of each major facility.

The principal emphasis of the system planning process is on the forecast load about fourteen years into the future and the generation alternatives available to meet that load. This essentially confines the choice to those technologies that are then currently technically and environmentally feasible and cost competitive. To maintain the maximum flexibility in the face of changing loads, projects are not committed until they are considered essential to maintain system reliability.

In this chapter we will discuss some of the major components of the system planning process.

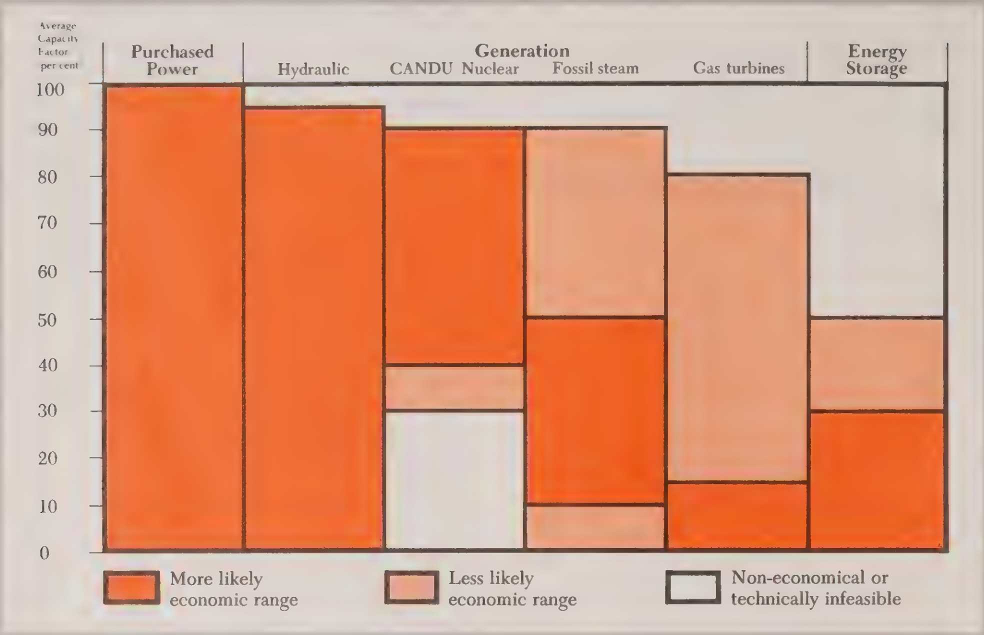
Capacity Planning

The system planning process begins with a forecast of "firm" peak load, which is total peak load minus industrial interruptible and any managed load. The objective is to design a system which will provide sufficient capacity, not only to meet the firm system peak load but also to accommodate contingencies that may affect the supply of electricity. These include equipment failure, unscheduled maintenance or shutdowns, low water levels and storm damage. The first category of generation called upon to accommodate these contingencies is known as "spinning reserve" because it is kept in constant readiness to accept load. If necessary, other reserves can be drawn upon with some time lag. "Reserve margin" is the quantitative expression of the total reserve available for operation as a percentage of annual firm peak load.

Determination of optimum reserve capacity involves a complex technical assessment of the probability of unexpected equipment failures (forced outage rate) and routine maintenance requirements. Utilities maintain detailed operating records to assist in this evaluation and to develop a forecast of what is known as the "availability factor" of their generating units (percentage of time that units are available to supply electricity). The large thermal units of Ontario Hydro have availability factors of about 77 per cent and the hydroelectric units 95 per cent. These availability factors are reflected in the amount of reserve capacity planned for the system.

The present Ontario electric power system requires a reserve margin in the order of 30 per cent to meet the current utility reliability criterion, which limits generating system failures to meet weekday peaks to only one day in ten years. (Assuming that there are 240 working days in a year, this criterion gives a "loss of load probability" of 1/2400th). Because thermal generating units have higher forced outage and maintenance requirements than hydraulic units, systems with a higher proportion of thermal generation require greater reserve capacity. North American experience has also shown that the very large thermal stations, whether nuclear or fossil, have higher forced outage rates, and hence lower reliability,

Figure 3.1 Efficient Operating Range of Alternative Types of Power Sources



SOURCE Ontario Hydro, *Generation Planning Processes*. Memorandum to the Commission, May, 1976 p.70.

than smaller plants do. Net energy output per kilowatt is thus less for such units.[1] Reserve requirements also increase with the size of individual units in relation to the size of the system.

Incremental reserve capacity tends to increase more than proportionately to the increase in unit size. If in the future, Ontario Hydro adds 1250 MW nuclear units with an estimated forced outage rate of 12 per cent, instead of the currently committed 850 MW units which have an estimated 10 per cent forced outage rate, an incremental reserve capacity of 400 MW per unit or 32 per cent of the unit capacity would be required, as compared to 160 MW or 19 per cent of the capacity of the smaller units.[2] We examine some of the offsetting benefits of the larger units in a discussion of economies of scale in Chapter 7.

The ratio of energy delivered by a generating unit over a given time period to the maximum energy which could be delivered if the unit operated continuously at peak capacity is called its "capacity factor". New capacity additions are planned for use in one or more of the following four modes based on capacity factors: base load, intermediate load, peak load, and reserve. All generating units operating at annual capacity factor of 55 per cent or more are classified by Ontario Hydro as base load units. Intermediate load units operate at capacity factors from 10 to 55 per cent and peak load units operate at capacity factors of less than 10 per cent.

Based on the foregoing definitions and the assumed annual pattern of demand, Ontario Hydro estimates that the base load component will constitute about 69 per cent of capacity (and supply over 89 per cent of energy), the intermediate load component almost 22 per cent of capacity (and over 9 per cent of energy) and the peak load and reserve component the remainder. Generation planning attempts to match technologies to these requirements, taking into account their technical and economic suitability for particular modes of operation, their capability to respond to increases or decreases in load (i.e., to "load-follow"), their capital costs, and the availability of input fuel. Figure 3-1 illustrates in a very general way the spectrum of technologies available for large-scale generation and three key economic characteristics of each technology.

Although in the past Ontario Hydro relied primarily on hydraulic power, since 1960 it has increasingly turned to thermal generation as the bulk of the economic hydraulic potential of the province was harnessed. Hydraulic power now accounts for less than 30 per cent of total electrical capacity.

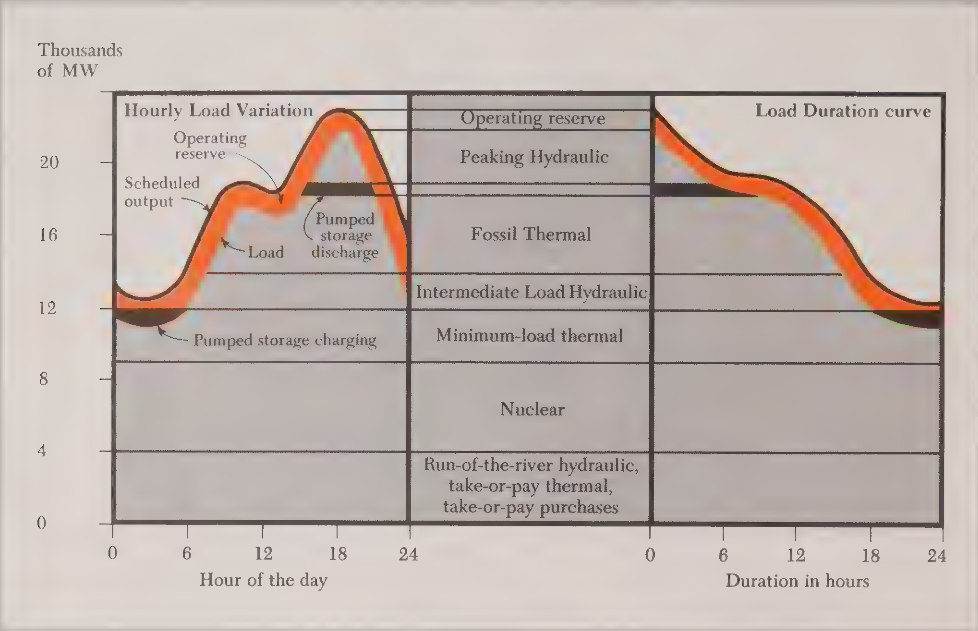
Large central thermal generating stations fuelled by oil, natural gas, coal and uranium now make the major contribution to the electrical supply. As a result, an assured supply of suitable fuel at competitive prices has become a key element in determining future commitments.

In recent years the price of oil has escalated sharply while, at the same time, the perceived security of supplies has decreased markedly. Accordingly, Ontario Hydro is not planning further large generating stations fired by oil. The availiability of supply to existing oil-fired stations is reasonably assured through the export policy of the National Energy Board which requires that domestic needs receive first priority. However, long-term reliability of supply of domestic oil is uncertain, depending on, among other things, government action to encourage the development of additional frontier or tar sands oil.

Ontario Hydro uses natural gas at the 1200 MW Hearn G.S. on the Toronto waterfront, mainly to meet air quality standards. But natural gas is becoming as costly as oil and it is widely considered to be a premium fuel which can be better used for other applications than "firing boilers". Ontario Hydro does not anticipate any increase of its present annual natural gas consumption.

As a result of these supply constraints for natural gas and oil the fossil component of Ontario Hydro's expansion programme is based on coal. Coal having a sulphur content low enough to meet environmental standards is available in limited amounts from the Eastern United States. Western Canada low sulphur coal is plentiful but transportation and handling costs are very high. Other minor coal sources are located in Nova Scotia and in Ontario at the Onakawana lignite deposit near James Bay where proven reserves are estimated to be sufficient for the lifetime requirements of a 1000 MW plant.[3] The Onakawana deposit is further discussed in Annex E.

Figure 3.2 Patterns of Electric Power Demand and Generation



Ontario Hydro now purchases most of its coal requirements from the United States, but recent contracts provide for the delivery within two years of 3.4 million tonnes of bituminous coal per year and 910 thousand tonnes of lignite from western Canada. By 1990, Ontario Hydro may be purchasing one-third of its coal from Canadian sources. Because low-quality coal and lignite, when used in existing stations, pose certain technical problems the utility is currently carrying out studies and tests to determine the future potential of these resources for Ontario.

Of all the fuels used by Ontario Hydro, only uranium is indigenous to the province, in potentially large quantities (see Chapter 9). Consequently, the utility's current long range expansion programme involves substantial dependence on uranium.

Mode of operation, availability of technology, and cost and availability of primary fuels are only some of the many factors influencing capacity planning. Others include relative costs of building and operating facilities, constraints related to health and safety, environmental effects, siting requirements and socioeconomic costs and benefits. These, as they relate to nuclear power, will be discussed in detail in other chapters of this report.

Load Shape and Load Control

One important consideration in the choice of future generation is the load shape or level and pattern of demand on the system. Although utility loads are affected by many variables — industrial loads vary with the state of the economy, residential loads vary with the temperature, and street lighting loads vary with the season — the aggregate load fluctuates with a reasonably predictable pattern on a daily and seasonal basis.

For a typical utility like Ontario Hydro, electric power loads on a weekday increase from a minimum during the early morning hours to a secondary peak between 11:00 A.M. and noon and a full daily peak between 4:30 and 6:00 P.M., after which they decrease slowly during the early evening hours and rapidly in the late evening (Figure 3-2). During weekends and holidays, loads are usually at much lower levels. Also shown in Figure 3-2 is the daily load duration curve which is obtained from the hourly variation of the loads. Any point on the load duration curve indicates the number of hours during which the load was greater than that corresponding to the point.

At an operational level, generating resources are fitted to the load pattern. In order to meet the daily load requirements, a so-called "stacking" order of generating units is employed. At the bottom of the order, generating stations (thermal or hydraulic) which are the most efficient and have the lowest fuelling costs are placed on base load service and operate virtually continuously. During the off-peak nighttime hours these base load units may provide electricity in excess of that needed immediately and can be used to operate any energy storage units in the system. As the load builds up during the day, older, less efficient, or more expensive to fuel thermal units are brought into service to meet intermediate load requirements. During peak demand periods, various peaking hydro, thermal and pumped storage units are brought into use. As loads diminish, units are removed from service in the reverse order until the base load situation prevails. Electric load also varies on an annual basis. Ontario Hydro is a winter peaking utility, with maximum demand on the system occurring in December and January, and much lower demands in the summer months.

The extent of daily and annual variation is indicated by system "load factors", which give the average load as a percentage of the peak load. The annual load factor for Ontario Hydro's East System is about 67 per cent, but on a winter work day it is 81 to 87 per cent. Load factor can change naturally over time through the influence of changing electrical end-uses and energy conservation measures. For example, electric space heating could worsen the annual load factor, but air-conditioning load could improve it. Some conservation measures which can produce worthwhile energy savings, such as turning off office lights at night, actually worsen a utility's load factor while others — for example, removing every third fluorescent tube in office light fixtures — reduce peak demands and may improve system load factors!

Much attention is now being given to improving load factors through "load management" programmes. These have the effect of reducing the system peak load and consequently the need for costly generating capacity. Load management involves shifting demand from peak periods to the off-peak or "valley" periods. There are two basic methods by which load management may be accomplished by a utility. One way is to design pricing incentives into the rate structure which will tend to mould customer behaviour to the desired pattern. These incentives can and should be based on differential supply costs of electricity. Lower rates for night-time use, as proposed by Ontario Hydro in rate structures now under consideration by the Ontario Energy Board (OEB), could provide the necessary financial stimulus to persuade industrial and residential users to move some power requirements to off-peak periods thereby helping to fill the night-time valley in the daily load curve.

Without attempting to predict what the outcome of the OEB review may be, we observe that acceptance of time-differentiated rates — both time-of-day and seasonal — is in the ascendancy across North America. Such rates are generally thought to track utility costs more accurately than existing rates and hence are superior on economic efficiency grounds. But not enough is known, certainly in Ontario, about customer response to rate variations to permit reliable predictions of the amount of load that would shift from peak to off-peak periods, or of the savings in capital and fuel costs that may result. We join with Ontario Hydro Chairman Robert B. Taylor who said in a recent speech that he hoped "to see emerge [from the OEB hearings] the plans for a new rate structure; one that will give more useful price signals to all consumers and thus encourage the efficient use of electricity".

Another method of load management, the effects of which are more certain than those from redesigning rates, is the control or switching off of certain loads during peak periods. One form of voluntary load management, interruptible power contracts, offers discounts to very large industrial customers in return for which Ontario Hydro is empowered to curtail service for varying periods of time for economy or emergency reasons. Currently such contracts permit the curtailment of some 785 MW, about half of which is estimated to be available for interruption at time of system peak.

It may be possible to achieve much more extensive reductions in industrial demand by controlling certain types of loads. There is no reason, for example, why appropriate incentives cannot be devised to ensure that the pulp and paper mills keep pulpwood grinders, driven by huge motors, off the daytime system peak. Certain types of residential loads, in particular water and space heating and cooling, where thermal storage can be readily incorporated, are suitable for direct curtailment by the utility. Water heater control is the chief method of residential load management in Ontario today, with about 150 MW potentially controllable at time of system peak. Eventually there could be direct control of other appliances as there is in some countries. The potential savings in capacity (and therefore in capital cost for generation) should be weighed against the costs of load control apparatus.

Ontario Hydro has taken the position that, as long as peaking hydraulic capacity is available on the system or can be harnessed at moderate cost, it should be used for peaking purposes in preference to incurring potentially larger costs for load management. It is argued that the longer term problem is to find ways to flatten the broad eight-hour and ultimately the sixteen-hour daytime plateaus to reduce requirements for fossil generation — but these are difficult areas for load management.[4] The right combination of storage systems (now at the pilot plant or demonstration stage) together with load management could, however, reduce capacity requirements.

The Select Committee of the Legislature Investigating Ontario Hydro, in 1976, recommended major load management action by Ontario Hydro to effect a 2500 MW reduction of peak load by 1985 (an 8 per cent reduction in relation to the LRF 48A programme).[5] The Ontario Ministry of Energy accepted this recommendation only in modified form in the belief that the target is too high. Present Ontario Hydro estimates of load management potential, in published Hydro documents, are much

lower than the Select Committee target. One report puts the target for "managed consumer load" in 1985 at 500 MW with an additional 900 MW possible from voltage reductions and "public appeals". However, Ontario Hydro is at present engaged in major studies and field trials of load management potential; we understand that these will probably result in higher targets than those extant. We share with this Select Committee of the Ontario Legislature the belief that Ontario Hydro should pursue a vigorous programme in both the load management area and the development of pricing incentives to encourage a shift to the greater use of off-peak power.

Some natural variation in load, particularly on a seasonal basis, is claimed to be beneficial. For example, Ontario Hydro takes advantage of seasonal load variations by scheduling maintenance in the low demand summer months, thereby maximizing the capacity available at time of winter peak. Seasonal load variation also provides opportunites for exporting power, which can be quite profitable.

Ontario Hydro's System Expansion Programme

The present Ontario Hydro power system incorporates a well-balanced, diverse mix of generation. For example, in 1977, nuclear and coal-fired plants each provided about one-quarter of the province's electric energy, hydraulic plants supplied one-third, and natural gas and oil generators provided 3.9 and 1.5 per cent respectively. (The remaining 13 per cent was purchased from out-of-province utilities.) Natural gas and oil-fired plants, being expensive to fuel, are used for peaking purposes only, but in emergencies they can be used at higher capacity factors and thus provide flexibility to the system.

Under the currently committed programme (LRF 48A) and the current load forecast, best estimates of generation utilization indicate that fossil-fired generation will drop slightly to provide 30 per cent of total electric energy requirements in 1983, hydraulic generation and purchased power will decline to 27 and 3 per cent respectively, and nuclear generation will increase dramatically to 40 per cent. When the last unit of the committed programme comes into service in 1987, nuclear generation will be providing over 60 per cent of the province's electric energy requirements.

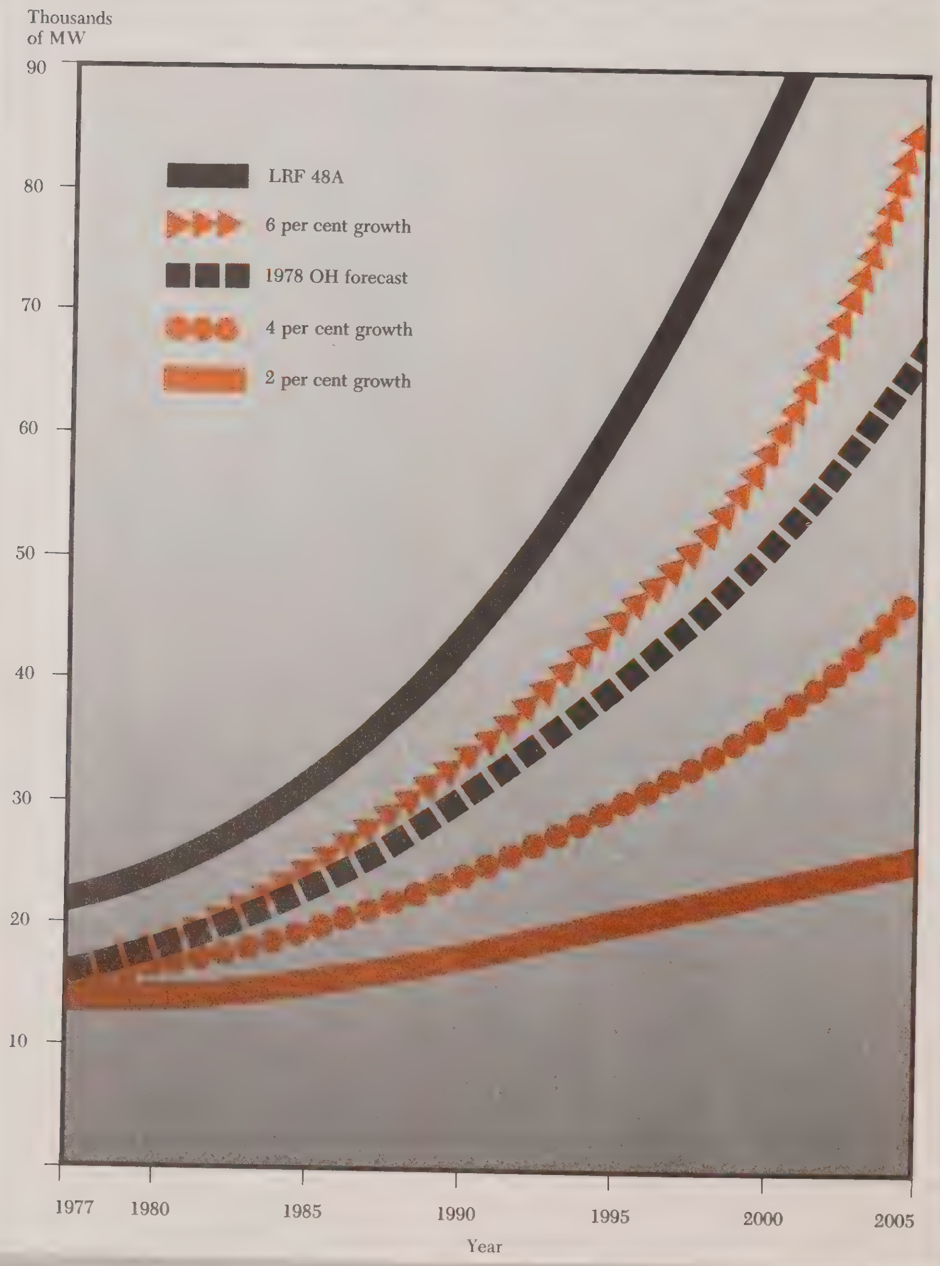
The future programme, beyond that now authorized or "committed", is based on CANDU and coal-fired stations; the nuclear units to be used primarily for base load, and possibly for intermediate load later in their operating lives, and the coal-fired units for intermediate load and peaking.

Although nuclear units demonstrate a continual "scaling-up",[6] coal-fired units, because of technical limitations, are stabilized at 750 MW. Further, adjustments made to in-service dates indicate a preference on the part of the utility to defer or cancel fossil rather than nuclear plants. The policy is to retain the maximum nuclear capacity consistent with any externally-imposed constraint (such as capital availability). Ontario Hydro has made nuclear power a key element in its system expansion programme, on the basis that not only will this strategy increase the security of fuel supplies but it will also minimize long-term total unit energy costs. We examine this latter proposition in some detail in Chapter 7.

During the past few years the emerging importance of factors which had previously been considered somewhat peripheral to the utility planning process has become apparent. An example is the rapid growth in the unit cost of generating plant and the consequent need to raise unprecedented amounts of capital. The emphasis on capital-intensive nuclear generation, combined with rapid cost escalation, has caused Ontario Hydro's proposed capital expenditures to grow to rather colossal levels.[7] Indeed, two adjustments to the system expansion programme were made in direct response to government policy directions to reduce borrowings[8] or capital expenditures.

There has also been great uncertainty associated with load growth, lead times, and economic costs. Adjustments have been traumatic. Cancellation of any committed projects is seen as a "last resort" measure, in view of the associated cancellation charges and potential layoffs.[9] The slower rate of direct employment creation associated with slower rates of expansion is itself emerging as a key

Figure 3.3 Ontario Hydro East System Capacity Plan and Peak Demand Scenarios



aspect of the debate on the future direction of the system expansion programme.[10]

As capacity forecasts were being adjusted downwards, load forecasts were also following a downward trend. However, until the 1978 load forecast, these adjustments were not enough to maintain preferred reserves and reliability levels. The possibility of brown-outs and black-outs as a result of inadequate generation was thus raised with the announcement of each new LRF between 1975 (LRF 43A) and 1977 (LRF 48A). The situation in 1977 was considered serious enough to warrant a major emphasis by Ontario Hydro on electricity conservation programmes.

The 1978 load forecast heralded a significant departure from the usual relationship between load and capacity forecasts. The very substantial drop in forecasted load over the medium term, part of which was attributed by Ontario Hydro to the success of its conservation initiatives, will no doubt result in an even greater deferral of capacity than that which resulted from the capital limitations. Figure 3-3 demonstrates graphically that, even allowing for a 25 to 30 per cent reserve margin over peak load, capacity additions called for in the current programme will exceed requirements, not only of the highest load growth scenario considered in the previous chapter (6 per cent) but also of Ontario Hydro's own 1978 load forecast. As indicated earlier, capacity committed for 1985 under LRF 48A is some 3000 MW in excess of that required under the 1978 load forecast to maintain preferred levels of reliability. This surplus was reduced to about 1900 MW by subsequent amendements to the programme. Projected reserve margins associated with the reduced programme remain well in excess of those required to meet utility reliability targets. Based on the current capacity expansion plan (LRF 48A) and the 1978 load forecast, the East System reserve margin decreases from 48 per cent in 1978 to about 38 per cent by the mid 1980s, after which it increases steadily to 66 per cent in 1995. On April 18, 1978, the Ontario Government announced its intention to pursue markets for power exports in order to utilize the excess capacity. And, as mentioned previously, adjustments to the longer term expansion plan to accommodate the implications of a slower growth in load are still under consideration by Ontario Hydro.

The Commission is aware of Ontario Hydro's efforts to incorporate new factors into the assessments of system alternatives; system expansion scenarios. An exemplification of this is the System Expansion Programme Reassessment (SEPR), which was initiated in response to the June 1976 report of the Select Committee of the Legislature recommending a significant reduction in the expansion programme and ambitious load management targets. The purpose of the SEPR project is to evaluate the socioeconomic costs and benefits of alternative system expansion programmes and to assess the costs and risks of either an excess or deficiency in system capability to meet the load. As originally proposed, three load forecast scenarios, which ranged above, at, and below the then most probable forecast were identified; however, the 1978 load forecast is approximately the same as the "low" scenario of the original SEPR terms of reference.

We have several reservations about the project. First, despite its scope the SEPR model does not include some of the key feedback loops necessary to trace the interrelationships between key system planning variables, especially the influence of electricity prices on load growth and the impact of capital borrowing constraints on both prices and system mix. Secondly, the project appears to be, to date, almost entirely "in-house" at Ontario Hydro. We believe that more involvement of staff of government ministries in such studies would be desirable. Thirdly, the early emphasis in the SEPR study on social and environmental assessment procedures does not appear to have been followed up.[11] Clearly, social and environmental impacts are of broad public interest and should be addressed on an ongoing basis in the assessment of system plans. Even if these effects are to a large extent site specific and not readily translated into a total system context, we believe the linkages between the total system plan and its component regional parts deserve special attention.

Availability of Sites for Nuclear Power Stations

The problem of finding sites for power stations is

closely associated with the system planning process. In a presentation to the Commission,[12] Ontario Hydro stated that several existing generating plant sites have sufficient land area to accommodate further generating facilities (beyond those already committed). The sites and their maximum potential additional capacity in megawatts are as follows:

Lennox — 7,000 - 10,000
Darlington — 8,000
Wesleyville — 5,000
Bruce — 3,000
Chats Falls — 2,000
Lambton — 1,500

for a total of between 26,500 - 29,500 MW. These estimates of potential capacity are somewhat theoretical. The added capacity at the larger sites is assumed to be nuclear (i.e., 3400 to 5000 MW per station). Because the maximum size for coal stations is about 3,000 MW per station, less coal capacity can be added at a given site. Air pollution restrictions would place an absolute limit on use of some sites for fossil generation. Further, if it proved necessary at any site to resort to cooling towers, the potential for capacity additions would drop about 50 per cent, because of the additional land area required.

Capacity requirements and therefore site requirements are directly influenced by the assumed load forecast. The LRF 48A programme, which is based on the 1977 forecast of 6.2 per cent annual growth, implies the addition by the end of the century of some twelve (4 unit) generating stations after Darlington is in service in 1988. We understand that it is Ontario Hydro's view that, to provide for the capacity additions required under the 1978 load forecast, some 4 to 5 new sites will need to be acquired in the 1980s. Without being specific about unit size or type of generation, assuming a 4 per cent growth rate, only 5 or 6 new stations would be required to 2000 after the Darlington station is in service. However, for reasons listed earlier, Ontario Hydro has discouraged speculation that all these could be located on lands already owned. Clearly, the process of acquiring sites for stations to be commissioned in the early years of the next century must continue through the 1990s. Representatives of public participation groups involved in Ontario Hydro-sponsored meetings to select generating sites, informed the Commission that the utility's position is that the reduction in the load forecast will make no difference to the timetable for site selection: sites will continue to be acquired as per the earlier schedule, and if not immediately required they will be "banked". We will be addressing the concept of land banking in our final report.

A Note on Net Energy Analysis

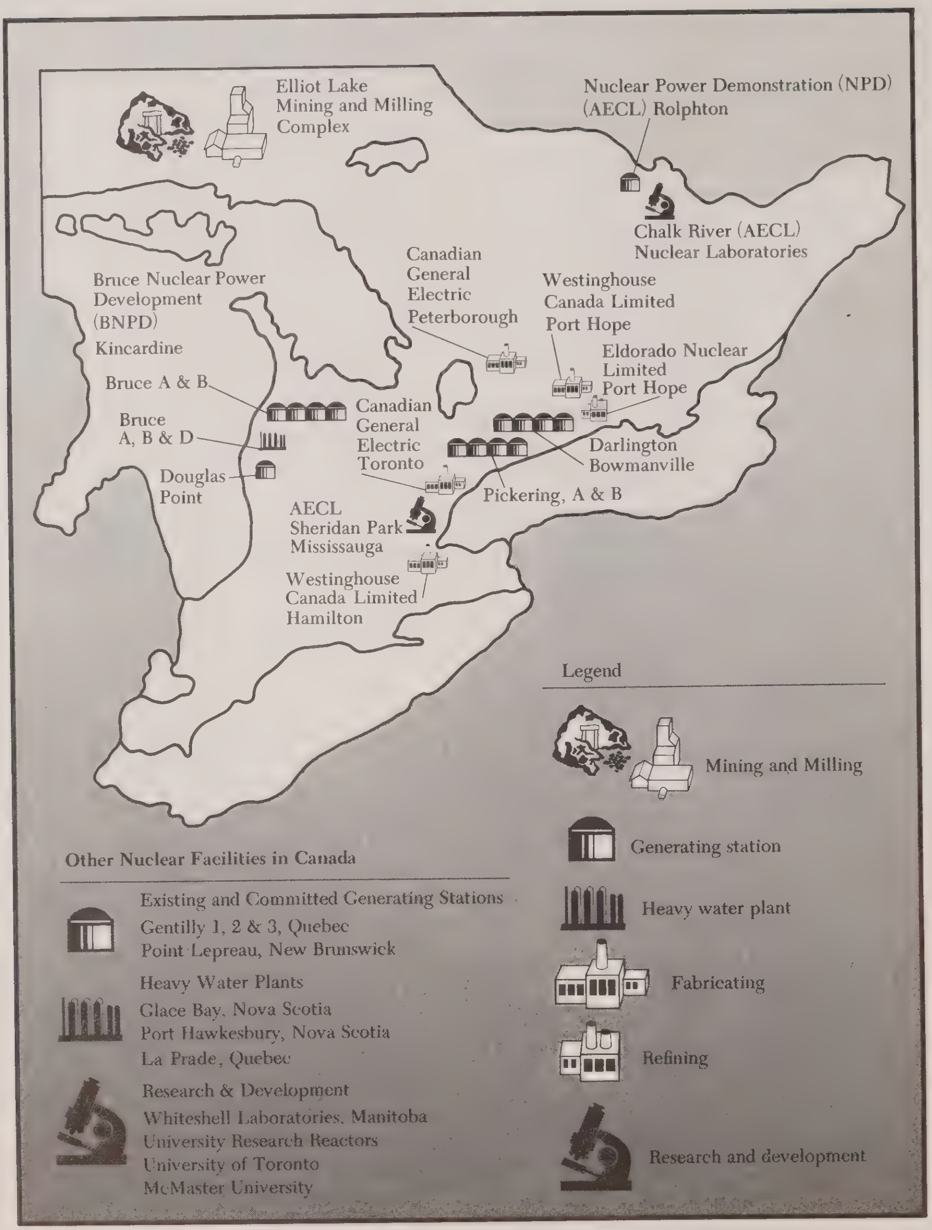
Several critics of nuclear power alleged at our hearings that nuclear power compared unfavourably with alternative energy technologies in terms of its net energy efficiency. Net energy analysis is a relatively new technique. Its purpose is to determine the amount of energy involved in providing for the delivery of a unit of energy to final consumers. Using static analysis, the total energy (a very complex quantity) required to construct a single energy generating facility and the total annual energy input are compared with the gross annual energy output to determine the "payback time", or number of years of operation required to produce an amount of energy equivalent to that required to build the facility in the first place. In contrast, a dynamic analysis deals with a multi-project programme, growing with time. A "net energy ratio" is calculated which represents the ratio of net energy output to the total energy being produced during a given time period.[13] This type of analysis is particularly important for facilities in which capital inputs are large relative to operating inputs.

In 1977, three federal departments undertook a net energy analysis of a two-unit CANDU station (units similar to Pickering A). It was found that, based on an 80 per cent capacity factor, the payback time would be between 1.2 and 2.1 years.[14] An Ontario Hydro study, using a different methodology, showed that the payback time would be between 0.85 and 1.1 years.[15] For a conventional coal-fired station, the federal group computed the payback time to be 0.31 years at a 60 per cent capacity factor. In the same study, the payback times for the Mackenzie Valley gas pipeline and the Syncrude Tar Sands oil extraction project were estimated to be 0.51 years and 0.43 years respectively.

The federal study also included a dynamic net energy analysis of an expanding CANDU nuclear programme which showed that at constant annual system growth rates, the net energy ratio decreases with an increase in growth rate, for example, from a respectable 0.87 under a 5 per cent annual growth rate to 0.53 with a 15 per cent annual growth rate. At growth rates of nuclear capacity of 25 to 30 per cent per year (beyond that credible for Ontario Hydro, but quite possible for a utility just commencing a nuclear programme), the ratio becomes negative, that is the programme consumes more energy than it produces. The study also showed that with a constant annual growth rate there is a limit to the net energy output that can be obtained in any future year. The net output, in a given future year, increases initially as the growth rate assumed is increased, reaches a maximum and then decreases with higher growth rates. Thus a higher growth rate of electrical capacity does not necessarily result in a higher net energy output in a future year. The net energy ratio is also affected by lead times; in general it decreases with an increase in the construction lead times of a single facility.

Although net energy analysis is an interesting illustration of the energy implications of alternative technologies, we are aware of both methodological problems and limitations associated with its use in energy policy making. It is difficult, for example, to translate accurately all types of inputs and outputs (labour, material, dollars, electricity) into a common unit of energy. Indeed, there is disagreement among analysts even about the legitimacy of translating one form of energy into another at equal value. Is a joule obtained from uranium equivalent to a joule obtained from natural gas? Such questions are important because the "value" of a unit of energy depends as much on its end-uses as on its inherent energy content. Perhaps, fundamentally, energy efficiency need not necessarily reflect economic efficiency; in other words net energy savings may be achieved at such a cost in other scarce resources that the energy-efficient solution may turn out to be the most expensive overall.

Figure 4.1 Nuclear Facilities in Ontario and Canada



Chapter Four

The CANDU Fuel Cycle

An assessment of the implications of nuclear technology for Ontario necessitates a discussion of the total fuel cycle as well as its role in the total energy needs of the province. All stages of the CANDU (for CANadian Deuterium Uranium) fuel cycle are, in fact, carried out in Ontario (see Figure 4-1). The so-called "front-end" of the cycle includes the mining, milling and refining of uranium; production of heavy water; and the generation of electricity; while the "back-end" of the cycle involves the management of radioactive wastes. In this chapter, which begins with the historical background, we introduce, briefly, the technological aspects of each stage of the CANDU fuel cycle.

The Development of Nuclear Power in Canada

Although Canada's initial involvement with nuclear power is usually thought of in terms of her participation with Great Britain and the United States in the Manhattan Project (the wartime undertaking to develop an atomic bomb), it is interesting to note that, during the period 1898-1907, Professors Rutherford and Eve, at McGill University in Montreal, carried out some of the basic experiments in nuclear physics which laid the foundations of nuclear power.[1]

Furthermore, it was the inspired foresight of Dr. C.J. MacKenzie, then Acting President of the National Research Council, strongly supported by General A.G.L. McNaughton, which led to the establishment of Canada's first "fission-age" nuclear laboratories in Montreal in 1943, a secret wartime facility. The first Director of the Atomic Energy Division of the National Research Council was the distinguished British physicist, and subsequent Nobel laureate, Sir John Cockcroft. He headed a team of Canadian, British and European scientists and engineers during the formative period, 1944 to 1946, of modern nuclear science and technology. The Atomic Energy Division subsequently moved to Chalk River, Ontario, where the now internationally renowned nuclear laboratories were established.[2]

The early research programmes at Chalk River emphasized heavy water as a reactor moderator. The results were subsequently applied to the design of heavy-water moderated reactors and to the chemical separation of plutonium. A very significant contribution was the zero energy experimental pile (ZEEP) which achieved criticality on September 5, 1945. It was the first nuclear reactor to operate outside the United States. This success, in turn, led to the decision to design and build the heavy water moderated research reactor (NRX) that achieved criticality on July 22, 1947.

Canada has never given serious consideration to the development of nuclear weapons. However, at the end of the war, this country was viewed as one of the three "atomic powers", and Prime Minister King was invited to attend the Atomic Conference held in Washington in 1945, together with President Truman and Prime Minister Attlee. The Conference was intended to bring the three governments together to agree on the co-operative peacetime development of atomic energy. Their discussions led to the establishment, in December 1945, of the United Nations Atomic Energy Commission. Its purpose was to facilitate the exchange of atomic information for peaceful purposes, to bring about the elimination of national atomic

weapons, and to establish effective international safeguards and inspection procedures. All member nations of the Commission were also members of the Security Council of the United Nations, with the sole exception of Canada. In keeping with Canada's decision to restrict her postwar efforts to the peaceful uses of nuclear energy, the Atomic Energy Control Board (AECB) was established in 1946. The Board was responsible for the control of all "prescribed" materials (fissionable and radioactive isotopes), as well as the monitoring of the atomic research and development being carried out by the National Research Council (NRC).

The NRU, a heavy water moderated reactor, was commissioned in 1958. A more complex research reactor than ZEEP and NRX, it laid the technological foundations for the CANDU family of power reactors. (Dr. W.B. Lewis, Director of Research of the Chalk River Laboratories, is the unchallenged "father of CANDU": it was his imagination, initiative and courage that launched and sustained the programme from the early days.) Shortly thereafter, discussions were initiated by federal government agencies and The Hydro-Electric Power Commission of Ontario (the forerunner of Ontario Hydro) which led to a feasibility study for a nuclear electric power station.

In 1952, responsibility for the Chalk River project was transferred from the National Research Council to the newly established Atomic Energy of Canada Limited (AECL), a Crown Corporation. Two years later, a nuclear power division was established at Chalk River; it was headed by Harold Smith (now a vice-president of Ontario Hydro), and included members from other Canadian utilities and from industry. The objective was to develop the design concepts for a prototype 20 MW Nuclear Power Demonstration (NPD), Pressurized Heavy Water (PHW) reactor. Proposals for the design and construction were requested from seven Canadian manufacturers, and Canadian General Electric was chosen as the contractor.

It was, however, an AECL statement in 1958 proposing a Canadian nuclear power development programme which set the course for this country's "nuclear future". Its primary objectives were to reduce dependence on foreign fuels by utilizing indigenous Canadian uranium and to provide a new and expanding opportunity for Canadian mining and manufacturing industries. In particular, the design of the reactor core was such that Canadian manufacturers were able to supply most of the components. Furthermore, a commitment to voluntary participation by Canadian industries with electric utilities was also made. This co-operative programme called for AECL to take the lead in advancing the national development of nuclear power until the private sector industries, and the utilities, could evolve independent capabilities in the field.

During the period when the nuclear industry and Ontario Hydro were designing and constructing the first large-scale CANDU-PHW power reactors — Douglas Point (200 MW) and Pickering A (four 500 MW units) — AECL was developing two innovative CANDU concepts; the boiling light water cooled reactor (BLW) at Gentilly, Quebec and an organic-cooled reactor (OCR) at the Whiteshell Laboratories, Manitoba. Neither of these designs has been pursued beyond the prototype stage, essentially because of a lack of research funding and not least because of the outstanding success of the PHW concept as exemplified in Pickering A and more recently in Bruce A.

All Ontario's existing and committed nuclear generating stations incorporate CANDU-PHW reactors (see Figure 4-1). For example, Pickering A and B incorporate four 500 MW units each, and Bruce A and B will each have four 750 MW units. Construction of the Darlington station has also begun; it will have four 850 MW units and the station is expected to come into full service about 1988. In addition to these Ontario stations, Canada's power programme to date includes: Gentilly 1, the prototype CANDU-BLW 250 MW reactor; Gentilly 2, a 600 MW CANDU-PHW reactor; and Point Lepreau, New Brunswick, another 600 MW CANDU-PHW reactor which is due to come on line in 1980. Gentilly 3, a 600 MW CANDU-PHW, has been committed by Hydro-Québec, but has not yet been scheduled.

The Canadian nuclear industry has developed slowly, albeit very effectively, largely because of the comparatively small domestic market. Government policy has been based on close co-operation

between AECL, the electric utilities (notably Ontario Hydro), and the private sector. The manufacturing and design capabilities of the latter have developed remarkably during recent years. In contrast, in Britain and the United States, all components of the nuclear design process were turned over to the private sector at an early stage; this approach has had mixed results.

AECL provides support, information and data to Canadian utilities and manufacturers in the nuclear sector, and holds seminars and symposia to facilitate communication. To carry out these responsibilities, research and development establishments are maintained at Chalk River, Whiteshell, and Sheridan Park near Toronto. The agency provides engineering services and monitors all nuclear facilities in the country. AECL is also responsible for the production of heavy water outside of Ontario and for the production of radiation material and equipment used in medicine and industry. Of the important medical advances, especially in the treatment of cancer, particular mention should be made of the Cobalt-60 Therapy Unit — these advances are essentially spin-offs from Canada's nuclear research.

Research contracts are placed with universities, provincial research councils and industries to support in-house activities. In addition, personnel are frequently seconded to AECL by utilities and industries for periods of up to two years for research and design experience, and in-depth training. Some of the research and development work carried out at Chalk River and Whiteshell is, in fact, partly funded by Ontario Hydro. Noteworthy too is the fact that AECL is currently increasing its budget and staff to deal with the problem of spent fuel management, particularly research to determine safe methods of radioactive waste disposal. Research programmes, such as the latter, are undertaken in close co-operation with other "nuclear" countries.

The relationship between AECL, Ontario Hydro, and the private sector continues to be close and co-operative.[3] It is unique in the world. Members from these three constituencies form an important part of the Canadian Nuclear Association (CNA), an organization founded in 1960 that "co-ordinates and represents the interests of governments, utilities, consulting firms, producers of essential materials, and manufacturing firms who are or expect to be engaged in some phase of development and/or utilization of nuclear energy".

Although AECL has the responsibility for export sales of CANDU reactors, and retains control of projects abroad, private industry is involved in the construction and engineering management of these projects. Within Canada, AECL undertakes the basic reactor design. However, Ontario Hydro has over the years developed an extensive in-house design capability in many aspects of the CANDU system. And only Ontario Hydro has experience in commissioning reactors. Indeed the utility has been called upon to commission all CANDU reactors for both domestic and foreign service as well as to train all nuclear operators.

The design and construction of the Darlington nuclear generating station provides an excellent example of co-operation between the major "nuclear partners". AECL is responsible for the design of the reactor cores and fuel handling systems; Ontario Hydro is responsible for the overall plant design, and for the conventional systems; and private industry designs and supplies the components, some of which are highly complex and specialized.

The Front-End of the Nuclear Fuel Cycle

The so-called "front-end" of the CANDU fuel cycle, shown schematically in Plate 1, Colour Section, involves the mining and milling of uranium, the fabrication of nuclear fuel and the production of heavy water. Uranium was first discovered in Ontario in 1953, in the Elliot Lake area. Soon after, a number of countries, and particularly the United States, contracted for large quantities of uranium for the development of atomic weapons. The result was a major development programme at Elliot Lake; twelve mines and eleven mills were brought into production between 1955 and 1958, with seven different companies owning and operating mining and milling facilities. However, the fortunes of the Elliot Lake area were reversed when the United States announced it would no longer purchase uranium from abroad but would support domestic producers. Contracts between the

United States Atomic Energy Commission and Elliot Lake producers were terminated in 1962, and most of the mines and mills were closed down, with the exception of the Denison and Nordic mines. The population of the town of Elliot Lake dropped from 25,000 in 1959 to about 7,000 in the early 1960s.

During the period when market conditions for uranium were depressed in the 1960s and early 1970s, the federal government established a joint federal government-Denison Mines stockpile. Over 6,000 tonnes of uranium remain in the stockpile and this is available on loan to Canadian utilities when necessary. In 1971 a federal Crown Corporation, Uranium Canada Limited (UCAN), was created to manage the stockpile.

Since the 1973 OPEC oil crisis, interest in long-term uranium contracts, as utilities seek to secure fuel supplies for their nuclear power reactors, has stimulated a new boom in the industry. For example, Ontario Hydro has recently signed contracts for the 1978-2020 period with Elliot Lake producers for up to 76,000 tonnes of uranium. Export contracts have also been signed with American, British, Japanese and Spanish agencies for deliveries to 1993. As a result, several mines are being reactivated and others are expanding production. The Denison property, Rio Algom's Quirke and Panel mines, and Preston's Stanleigh mines are all operating or actively preparing for production. Total Ontario mining and milling capacity may reach a maximum potential of approximately 6,000 tonnes per annum by 1985.

The Elliot Lake deposits are extensive but the concentration of uranium oxide (U_3O_8), the raw material required for nuclear fuel fabrication, is relatively low. The average concentration over the entire lifetime of the mining operations is expected to be about 0.5 kg per tonne.[4] In other words, each tonne of ore mined, raised to the surface, crushed and milled results in 0.5 kg U_3O_8 and one tonne of waste "tailings".

Approximately 80 million tonnes of these tailings, mostly from activities in the 1950s and early 1960s to produce uranium for use in the United States and the United Kingdom weapons programmes, lie on the surface and in the lakes of the area surrounding the mills (see Plate 2, Colour Section). To neutralize the tailings, which contain large quantities of radioactive radium, lime is added to the water in a neutralization tank and the resulting solution is discharged to the tailings pond where the heavy components of the effluent settle. The clarified water is then treated with barium chloride, which renders the radium-226 insoluble so that it precipitates out of the solution and slowly settles to the bottom of the pond.

Surveillance of waste disposal operations in the Serpent River Basin near Elliot Lake by the Ontario Ministry of the Environment and its predecessor goes back to 1957. At that time the only stipulations for managing this residue were that embankments should be constructed to contain the ponds which hold the tailings and that liquid effluents should be neutralized. The potential adverse effects of uranium mining and milling on health and the environment are considered in some detail in Chapter 6.

The extraction of the uranium oxide begins with the crushing and grinding of the ore. Sulphuric acid, steam and air are added to enhance leaching, followed by a separation stage where the waste residue is discharged to a tailings neutralization tank. The product stream goes through an ion-exchanger that removes the heavy elements. Nitric acid selectively removes the uranium from the ion-exchanger, and ammonia precipitates the uranium from the solution. The U_3O_8 (yellowcake) precipitate is collected, dried and packaged in drums for shipment to a refinery.

The Port Hope uranium refinery, currently the only facility of its kind in Canada, is operated by Eldorado Nuclear Limited, a federal Crown Corporation. It is equipped to produce natural uranium dioxide (UO_2) for use in CANDU reactors and uranium hexafluoride (UF_6), which is exported and used in the uranium enrichment process. Slightly enriched uranium (2 to 3 per cent) is used in light water reactors. The Eldorado facilities currently process about 6,000 tonnes of ore concentrate annually, more than two-thirds of which is mined in the Elliot Lake area.

The first few steps in the refining process are common to both uranium dioxide and uranium

hexafluoride production streams. After the incoming yellowcake is sampled and analysed, it is "digested" in a mixture of nitric acid. Treatment with an organic solvent (tributyl phosphate in kerosene) separates out a pure uranium compound, uranyl nitrate. Uranyl nitrate is the feedstock for the production of both uranium dioxide and uranium hexafluoride. The waste, or "raffinate" stream, contains the residual radium and other impurities removed from the uranium compound.

To produce the uranium dioxide needed for CANDU fuel, ammonium hydroxide is added to the pure uranyl nitrate solution. The resulting slurry of ammonium-uranium compound is "dewatered" and then fed through a drier. Heat transforms the compound to uranium trioxide (UO_3), which is reduced to uranium dioxide (UO_2) by the addition of hydrogen. Before shipping, the uranium dioxide is pulverized and blended in lots of up to 2000 kg. It is then shipped to one of the two commercial fuel fabricators in Ontario — Canadian General Electric in Toronto and Peterborough or the Westinghouse plants in Port Hope and Hamilton.

CANDU nuclear power systems are fuelled with ceramic grade natural uranium dioxide containing 0.7 per cent of the fissionable uranium-235 isotope. Since this concentration of uranium-235 is the same as that found in nature, it is known as "natural" uranium dioxide and can be burnt in a CANDU reactor without further concentration ("enrichment"). The fabrication of fuel for CANDU involves pressing, sintering, and grinding uranium dioxide powder into very dense pellets and subsequently sealing these in zirconium alloy tubing (see Plate 2, Colour Section). At this stage the fuel bundles can be handled without any risk to health.

The production of uranium hexafluoride for export is a somewhat more complex process. First, the uranyl nitrate is fed to electrical heaters that decompose it to uranium trioxide. The nitric acid is then recovered and reused. The uranium trioxide is treated with steam and hydrogen to produce uranium dioxide, which is then further treated with hydrofluoric acid to provide uranium tetrafluoride. Pulverized uranium tetrafluoride is burned in fluorine gas to make the final conversion to uranium hexafluoride. The gaseous hexafluoride stream is filtered and forced through a cold trap where the uranium hexafluoride is condensed. It is piped into shipping containers in this liquid form and solidifies as it returns to room temperature. The cylinders are then shipped to foreign enrichment plants for use in light water reactors (LWRs).

Heavy Water

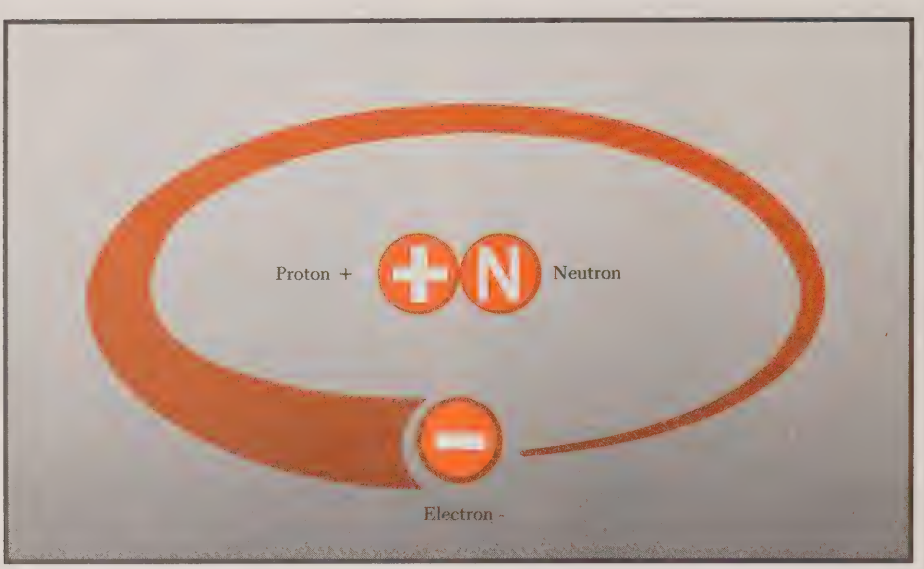
CANDU reactors use heavy water as both moderator and coolant. Chemically, heavy water (D_2O) is identical to ordinary (light) water. A D_2O molecule is made up of two deuterium atoms and one oxygen atom. Deuterium is an isotope of hydrogen. The nucleus of an atom of deuterium consists of one proton and one neutron and has twice the mass of the nucleus of hydrogen. Hence the term "heavy water" (see Figure 4-2). Similarly, tritium, an even "heavier" isotope of hydrogen, has a nucleus consisting of one proton and two neutrons. Ordinary water contains one part deuterium for 7000 parts hydrogen, or 0.014 per cent. This very small concentration must be increased to 99.8 per cent by mass for use in the CANDU reactor.

Heavy water is produced from ordinary water in a two-stage chemical process. In the first stage a 20 per cent concentration level is achieved using the Girdler-Sulphide technique. This process exploits the fact that hydrogen sulphide gas can be enriched with deuterium at high temperatures, and at low temperatures the deuterium migrates to the water feed. The water is continuously passed through a series of hot and cold towers until a 20 per cent concentration is reached. It is further enriched to 99.8 per cent heavy water by fractional distillation. Table 4-1 shows Canada's present and potential heavy water production capacity. The supply position as it relates to Ontario Hydro is dealt with in Chapter 7.

The Nuclear Generation of Electricity

A nuclear generating station has two major components as shown in Figure 4-3: the "nuclear furnace" and steam raising plant, and conventional equipment in which high pressure and temperature steam is converted into electric power. As shown schematically in Figure 4-4, the pressurized heavy water coolant which removes heat from the core of

Figure 4.2 Nucleus of an Atom of Deuterium



SOURCE Atomic Energy of Canada Limited.

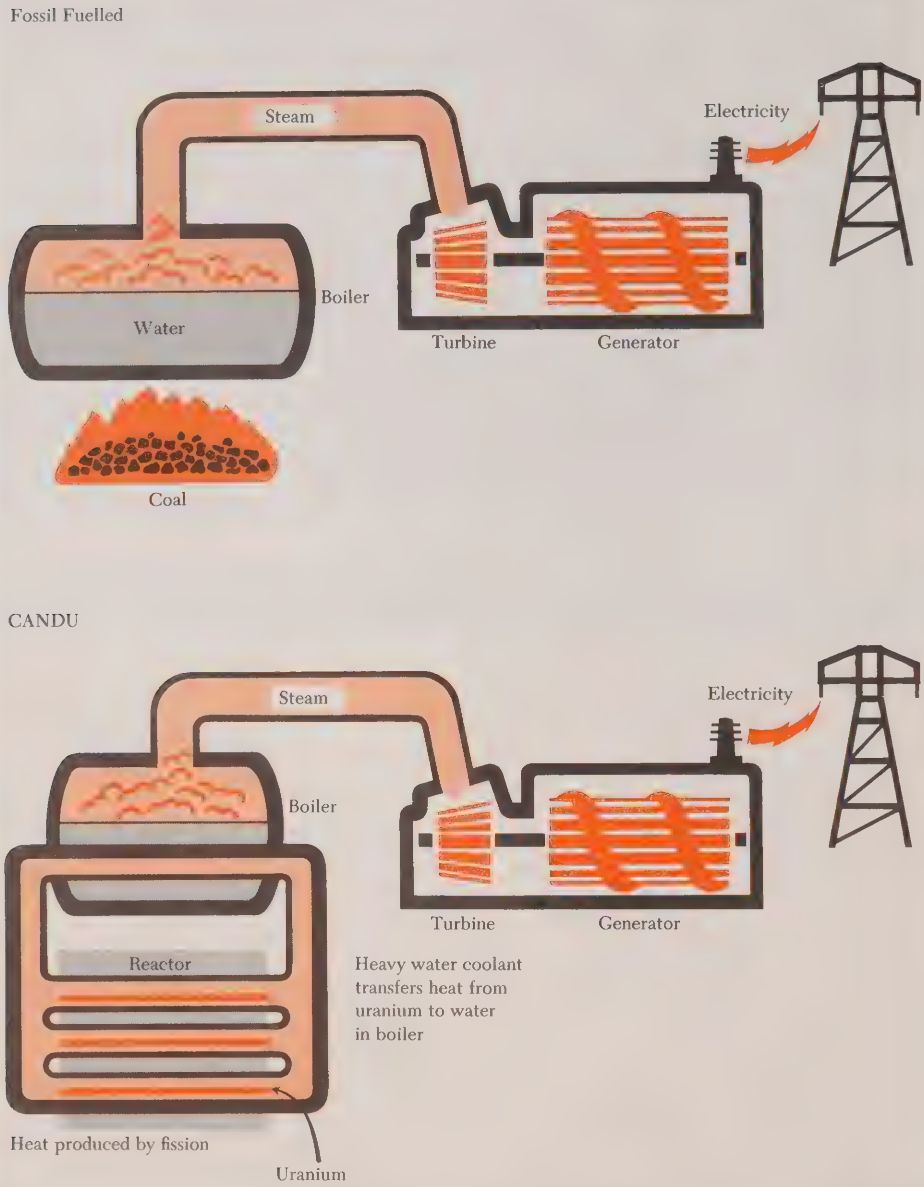
Table 4.1 Heavy Water Production Capacity

Plant	Owner/Operator	Annual Production Capacity at 100% * tonnes
Operating		
Bruce A	Ontario Hydro	856
Port Hawkesbury	AECL	[illegible]
Glace Bay	AECL	[illegible]
Under Construction		
Bruce B	Ontario Hydro	850
Bruce D	Ontario Hydro	[illegible]
La Prade	AECL	827

* Estimated long-term capacity:

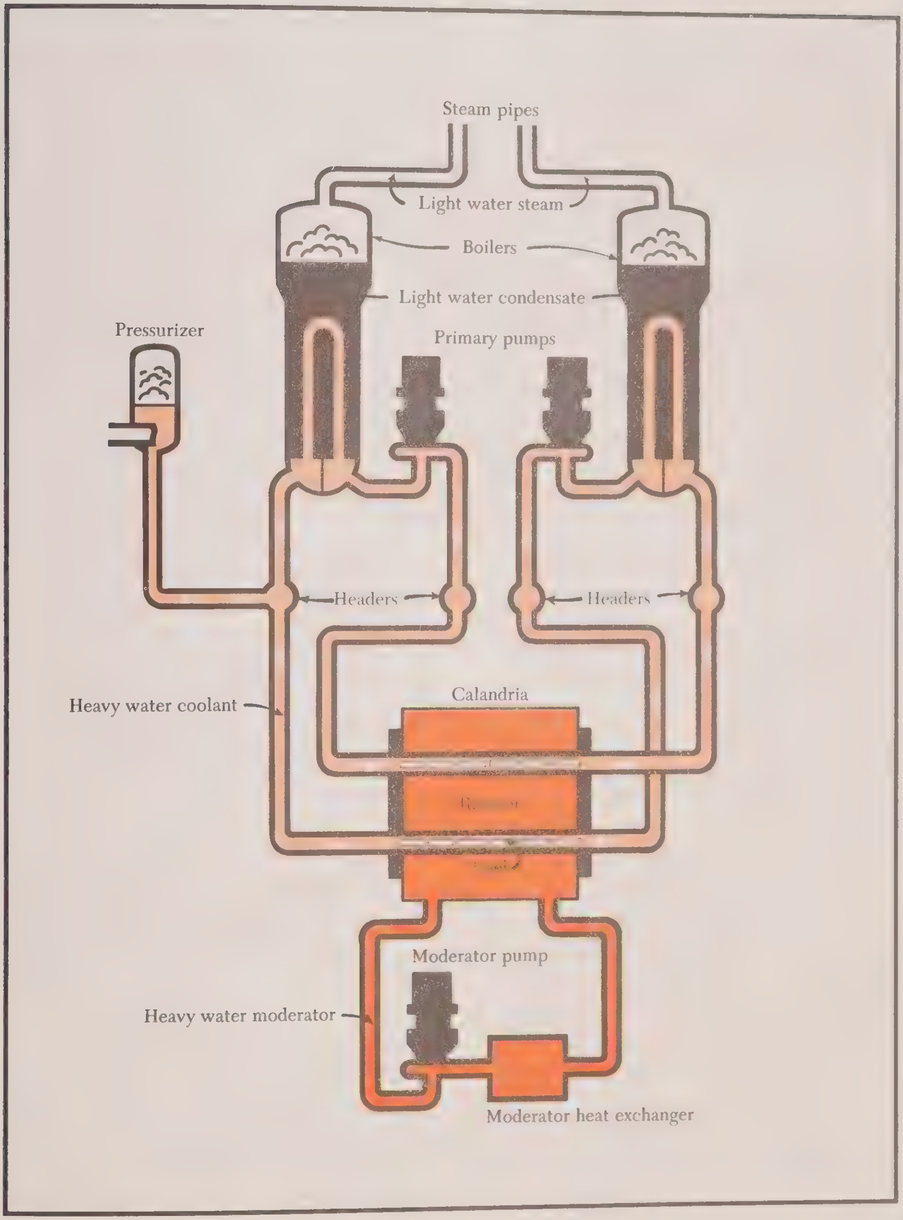
Dependable	63%
Probable	73%
Optimistic	80%

Figure 4.3 Operation of Fossil-Fuelled and CANDU Power Plants



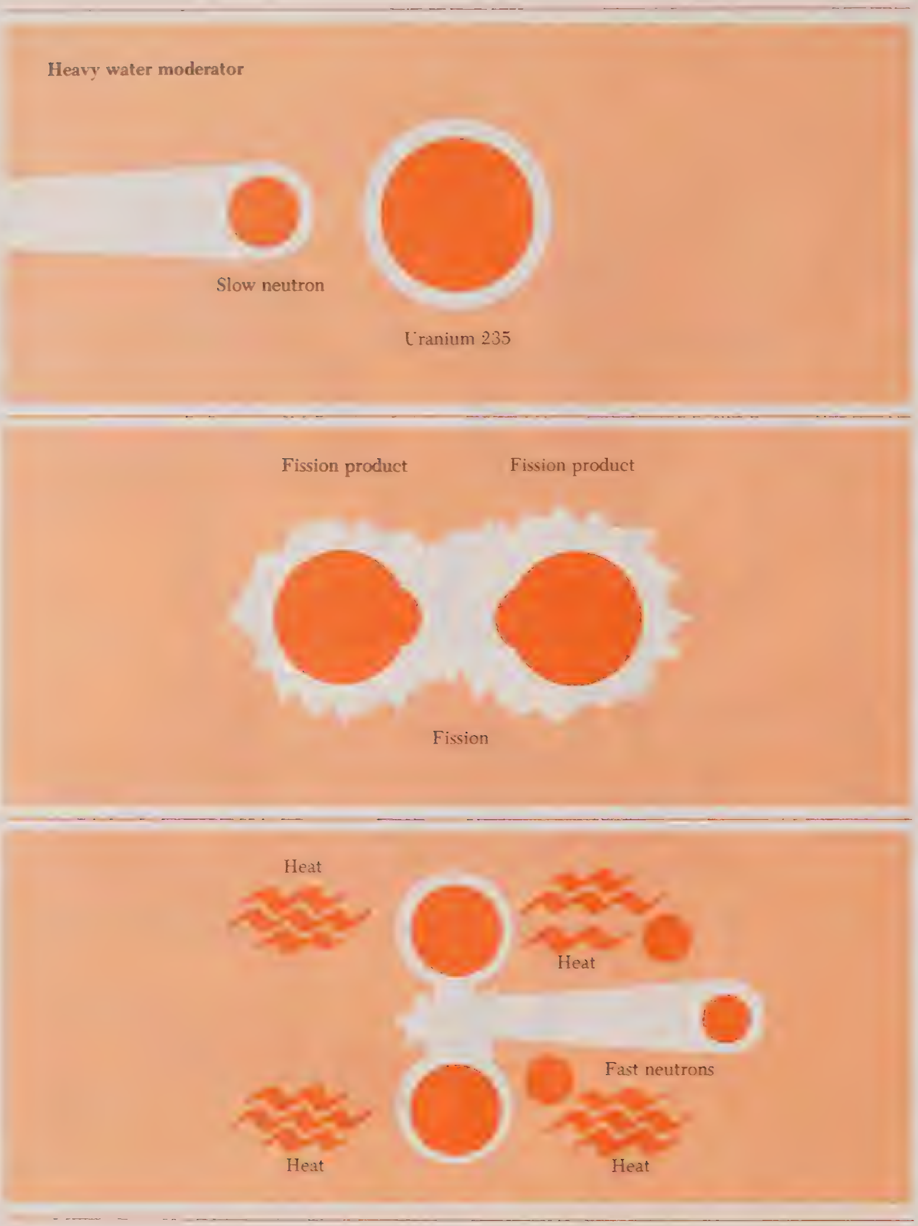
SOURCE Atomic Energy of Canada Limited.

Figure 4.4 CANDU Reactor Flow Diagram



SOURCE Atomic Energy of Canada Limited.

Figure 4.5 Nuclear Fission



SOURCE: Atomic Energy of Canada Limited.

the CANDU reactor is transported to the heat exchangers, or boilers, in which steam is generated. The steam turbine and electric generator system then convert the thermal energy of the steam into electric energy. As is the case with all "heat engines," there is an inherent loss of energy in the thermodynamic cycle. Consequently, the efficiency of a CANDU generating station is in the order of 29 to 30 per cent as compared, for example, with typical efficiencies of about 31 per cent and 35 to 40 per cent for LWR stations and coal-fired stations respectively.

An elementary knowledge of the basic concepts of nuclear physics is essential to an understanding of the nuclear furnace. Several excellent elementary texts, including some paperbacks, fill this need admirably (see the Bibliography). Some of the many fundamental physical laws and concepts that underpin nuclear power can be stated simply as follows:

- The laws of conservation of energy and mass are fundamental to modern science. For example, under some circumstances (notably in the creation of stars and their eventual demise), energy may be converted into matter, and matter may be converted into energy. In the case of nuclear fission a small fraction of the weight of the fissionable material is converted into energy. In a very real sense mass and energy are equivalent. The relationship between them is expressed in Einstein's law, based on his theory of relativity, $E = mc^2$, in which E is the energy equivalence of a mass m and c is the velocity of light. Note that the conversion of even a microscopic quantity of matter produces a very large amount of energy because c^2 is a very large number.
- The nucleus of an atom is made up of two types of particles of about equal mass, the neutron and the proton. The neutron has no electric charge and the proton has a positive charge equal in magnitude but opposite in sign to that of an electron. Nuclei having the same number of protons but different numbers of neutrons are referred to as isotopes. The chemical properties of an element are in no way affected by the number of neutrons in the nucleus and hence all isotopes of an element have the same chemical properties.[5] (As mentioned previously, normal hydrogen and the isotope deuterium, i.e. heavy hydrogen, have the same chemical properties.)
- The basis of nuclear power is associated with what is referred to as the "binding energy" of the nucleus. It has been demonstrated experimentally that the mass of the nucleus is very slightly smaller than the sum of the masses of each of the individual neutrons and protons. This difference is the binding energy and is, of course, a manifestation of the equivalence between mass and energy. The average binding energy per nucleon (a neutron or proton) is normally greater for the light elements and decreases with the mass number of the element. For example, the binding energy per nucleon in heavy elements such as uranium and plutonium is less than in lighter elements such as sodium and iron. But more important is the fact that the nuclei of the heavy elements may be comparatively unstable. The isotope uranium-235 is a case in point.
- It is important to distinguish between chemical reactions which involve a rearrangement of the outer electronic orbits of atoms, and nuclear reactions which involve a rearrangement of the protons and neutrons within the nuclei of atoms.[6] Nuclear power results from nuclear reactions of a special kind. When atoms of uranium-235 are bombarded with low energy (thermal) neutrons there is a high probability that the uranium nucleus will split into two fragments of unequal mass. This splitting process is called fission (see Figure 4-5). Only three radioactive isotopes — namely U-235, U-233 and Pu-239 — are known to undergo thermal neutron fission, and of these only U-235 occurs in nature. The process of fission gives rise to the release of a comparatively large amount of energy essentially in the form of the kinetic energy of the fission products which are ejected from the uranium nucleus with high velocities.
- Another very important nuclear reaction relates to "fertile" isotopes. From the standpoint of nuclear power the most important are uranium-238 and thorium-232. The nuclei of these isotopes are not fissionable by thermal neutrons, although fission can take place if the nuclei are bombarded with high energy neutrons. If nuclei of U-238 capture a neutron, a sequence of nuclear reactions

takes place which culminates in the production of Pu-239. Similarly, if nuclei of Th-232 atoms capture a neutron, U-233 is ultimately produced. These nuclear transformations can take several days.[7] Both Pu-239 and U-233 have essentially unstable nuclei which are readily fissionable by low energy neutrons.

- When the fission of, say, U-235 is initiated, two or three high energy neutrons, as well as fission products, are ejected from the uranium nucleus. If natural uranium is used, these high energy neutrons must be slowed down by the use of a "moderator" in order to increase the probability that they will be captured by other U-235 nuclei which, in turn, will fission and create more neutrons. In this way, a nuclear chain reaction can be established and if an adequate amount of U-235, in an appropriate geometrical configuration, is present, a high level of energy is released. Although the fissile elements are the same, in the nuclear bomb the chain reaction takes place at fantastic speed. Within millionths of a second the mass releases a tremendous amount of energy. The nuclear weapon is "uncontrolled fission". The nuclear reactor is "controlled fission". The former requires very pure fissile materials, while in the case of the nuclear reactor the fissile material is comparatively dilute. In the case of CANDU the proportion of U-235 in natural uranium is only 0.712 per cent.

Previously, we discussed the production of heavy water as an integral part of the front-end of the CANDU fuel cycle (see Plate 4, Colour Section).[8] We are now in a position to appreciate its central role in the development of a controlled nuclear reaction in a CANDU reactor. Heavy water slows down (moderates) the high energy neutrons and only a small proportion of these neutrons are lost through capture, producing a radioactive isotope of hydrogen, tritium (H-3). Light water is much less effective as a moderator because of excessive neutron capture. Light water reactors must therefore use uranium enriched with 2 to 3 per cent U-235 in order to make up for the neutrons which are captured. In spite of the complex technology involved in producing enriched uranium fuels (in CANDU the corresponding process is the "enrichment" of ordinary water to produce heavy water), LWRs are widely used on a global scale.

Uranium fuel bundles (see Plate 4, Colour Section) are loaded and unloaded into the pressure tubes which run horizontally through the calandria using two fuelling machines. During start-up, the calandria, a large "tank" which surrounds the core of fuel-bearing pressure tubes, is gradually filled with heavy water. Adjuster rods, which absorb neutrons, are gradually removed until the reactor goes "critical". A 500 MW CANDU reactor (e.g. Pickering A) contains about 100 tonnes of natural uranium and hence, about 712 kg of U-235. The commissioning phase of CANDUs, which may take several weeks, has been remarkably successful, and the teams of engineers and scientists responsible have broken several world records for the speed with which the commissioning process has been completed.

Some Unique Features of CANDU

The CANDU reactor is the only commercially available reactor which uses heavy water as moderator, natural uranium as fuel, and pressurized heavy water as coolant. Its "neutron economy", in consequence, is the most efficient of all commercially available reactors. For example, CANDU burns uranium about one-third more efficiently than the LWR.

CANDU possesses several unique design and operating characteristics that make it a highly significant contribution to the world's nuclear technology. For example, in the majority of nuclear reactors, the fuel and the moderator are enclosed in a large pressure vessel. CANDU, however, incorporates pressurized zirconium tubes which run horizontally through the calandria and contain "bundles" of uranium fuel pellets. Heavy water coolant under pressure flows through these tubes to remove the fission heat. This design is considered to be more efficient and safer than the pressure vessel configuration characteristic of the LWR, because the possibility of catastrophic vessel failure is avoided by using large numbers of tubes (390 per reactor for the Pickering station). Furthermore, unlike other reactors, CANDU can be refuelled while operating at full power. This feature contributes to the safety, efficiency and economy of the system.

Because of CANDU's cylindrical calandria,

special steps must be taken to obtain homogeneity of the neutron flux density in the core to avoid a situation where some parts of the core become "hotter" than others. The computer control (two back-to-back computers are used to ensure maximum reliability) of core neutron flux is amongst the most sophisticated in existence. As well as optimizing the overall performance of a reactor (the energy produced per tonnes of natural uranium fuel), this facility enhances reactor safety (see Chapter 6).

From a design standpoint CANDU technology is extremely flexible. For example, an alternative coolant, such as an organic liquid, can be used and, at least theorectically, CANDU can be adapted to burn several alternative mixed oxide fuels based on thorium, uranium and plutonium. Use of these mixed oxide fuels would obviously extend the life of uranium supplies. (So, of course, would the commercialization of the "fast breeder" reactor at present under development in several European countries.) Finally, because of the pressure tube concept, CANDU reactors are not particularly "dimension limited," as is the case with the present generation of LWRs. The potential capacity of the CANDU reactor — by increasing the size of the calandria and the number of pressure tubes — is at least 1250 MW.

CANDU, however, has certain disadvantages. The capital costs, per kilowatt, of a CANDU generating station are about 20 per cent higher than those of a comparable light water reactor. Much of this price differential is in fact due to the high cost of producing heavy water, the present price of which is approximately $210 per kilogram. Because radioactive tritium is produced in the normal operation of a CANDU reactor, both the coolant and moderator are to some extent radioactive. Furthermore, tritium is a highly radioactive gas with a half-life of about 12 years and is very difficult to contain. However, tritium releases have been kept well below the limits set by the AECB. This and other CANDU environmental concerns, including those associated with the production of heavy water, are considered in Chapter 6.

A further undesirable feature of the CANDU reactor is that an increase in reactivity occurs in the core if a void takes place in the pressure tubes. For example, a loss of coolant accident would cause a voiding of the pressure tubes as the coolant, no longer under high pressure, begins to boil. Such an accident would result in a temporary increase in reactivity at a time when it is crucial that the reactor be shut down as quickly as possible. This "positive void" is unique to the CANDU pressure tube design. The reactivity increase is small and is not believed to have serious safety implications.

Management of Low- and Medium-Level Radioactive Wastes

The routine operation of a nuclear reactor gives rise to large volumes of low- and medium-level radioactive wastes, as well as small volumes of highly radioactive wastes in the form of spent fuel (see Plate 6, Colour Section).

The low-level solid wastes consist essentially of protective clothing and boots, rubber gloves, and miscellaneous cleaning utensils and materials. These wastes are transported in special containers from, for example, the Pickering to the Bruce generating station. At Bruce the combustible material is incinerated in a special facility. The resulting ash is classified as medium-level waste and disposed of accordingly. The non-combustible material is buried in engineered structures within a special zone of the Bruce nuclear complex.

The medium-level radioactive wastes include ion exchange resins, special filter media and solidified liquid concentrates. All medium-level wastes produced in the province are shipped in heavily shielded containers to the Bruce disposal facility. This consists essentially of a series of large, engineered concrete "tile holes" which cover an area of about five hectares.

We have examined the handling and disposal processes at Bruce and we are satisfied that the precautions being taken are adequate and compare very favourably with similar handling and disposal facilities we visited in several other countries. We understand, moreover, that the Ontario Hydro's low- and medium-level waste disposal facilities are equal to or superior to those at present generally in use in Europe and the United States. In the United States low-level solid wastes are buried in canisters, and medium-level solid wastes are buried in unused mines; in the United Kingdom, they are

disposed of in the ocean. The Bruce facility is fully instrumented to measure both radioactive levels and temperatures and is monitored and inspected on a continuing basis by the AECB. Because the volume of low- and medium-level wastes will probably reach major proportions within the next 40 to 50 years, the disposal problem will necessitate the development of further large-scale facilities.

The Back-End of the Fuel Cycle

The CANDU fuel cycle is a "once-through" cycle in which no attempt is made to recycle the irradiated (spent) fuel. Plate 1 of the Colour Section, indicates that the "back-end" of the fuel cycle relates solely to the management of the spent fuel — its short-term storage, its interim-term storage, its transportation and its ultimate disposal. Furthermore, the question of how a nuclear power station will be "decommissioned" at the end of its useful life, which is normally regarded as between 30 and 40 years, must be addressed. It is clear that many components of the reactor building, especially of the reactor core, will be highly radioactive. Consequently, the process of decommissioning a nuclear plant will be a very complex one.

All CANDU spent nuclear fuel is currently stored in large water-filled pools or bays on the plant site. This is a universally used method of storing spent fuel for an interim period.

Because of the health, environmental and safety implications of all aspects of the back-end of the nuclear fuel cycle, not least the ultimate disposal of high-level radioactive wastes, we defer consideration of them until Chapter 6, in which we consider the total fuel cycle from these points of view.

Advanced Fuel Cycles

What is the potential for CANDU in which the spent fuel is recycled (closed loop fuel cycles)? We refer to these as spent fuel cycles (see Annex F).

Each year, the spent fuel discharged from a 750 MW CANDU reactor contains about 165 kg of unburnt U-235 and 262 kg of Pu-239. The potential of this fissile material to produce electric power is very considerable. It has been estimated, for example, that the energy content of the spent fuel (the Pu-239 component only) presently stored in the Pickering A spent fuel bays is equivalent to 150 million barrels of oil and is increasing at the rate of 25 million barrels of oil each year.[9]

The key question, which is discussed in Chapter 6, in connection with the problem of the interim storage of spent fuel, is whether this fuel should be reprocessed and the resulting Pu-239 recycled. Essentially, advanced fuel cycles could be based on the use of either Pu-239 (from present spent fuel) or U-233 ("bred" from thorium-232). The basic aim of all advanced fuel cycles is to conserve non-renewable uranium resources. The potential of fuel cycles which use Th-232 as a "fertile" isotope is particularly interesting because, on a global basis, it is thought to be about four times as abundant as uranium. The fundamental steps involved in "advanced fuel cycles" are shown schematically in Annex F. Essential to all advanced nuclear fuel cycles is a "chemical reprocessing plant" to extract Pu-239 from spent CANDU or LWR fuel, or, in the case of the "thorium cycle", to extract U-233 from the spent fuel. The unburnt U-235 in CANDU and LWR spent fuel is not retrievable by chemical processing.

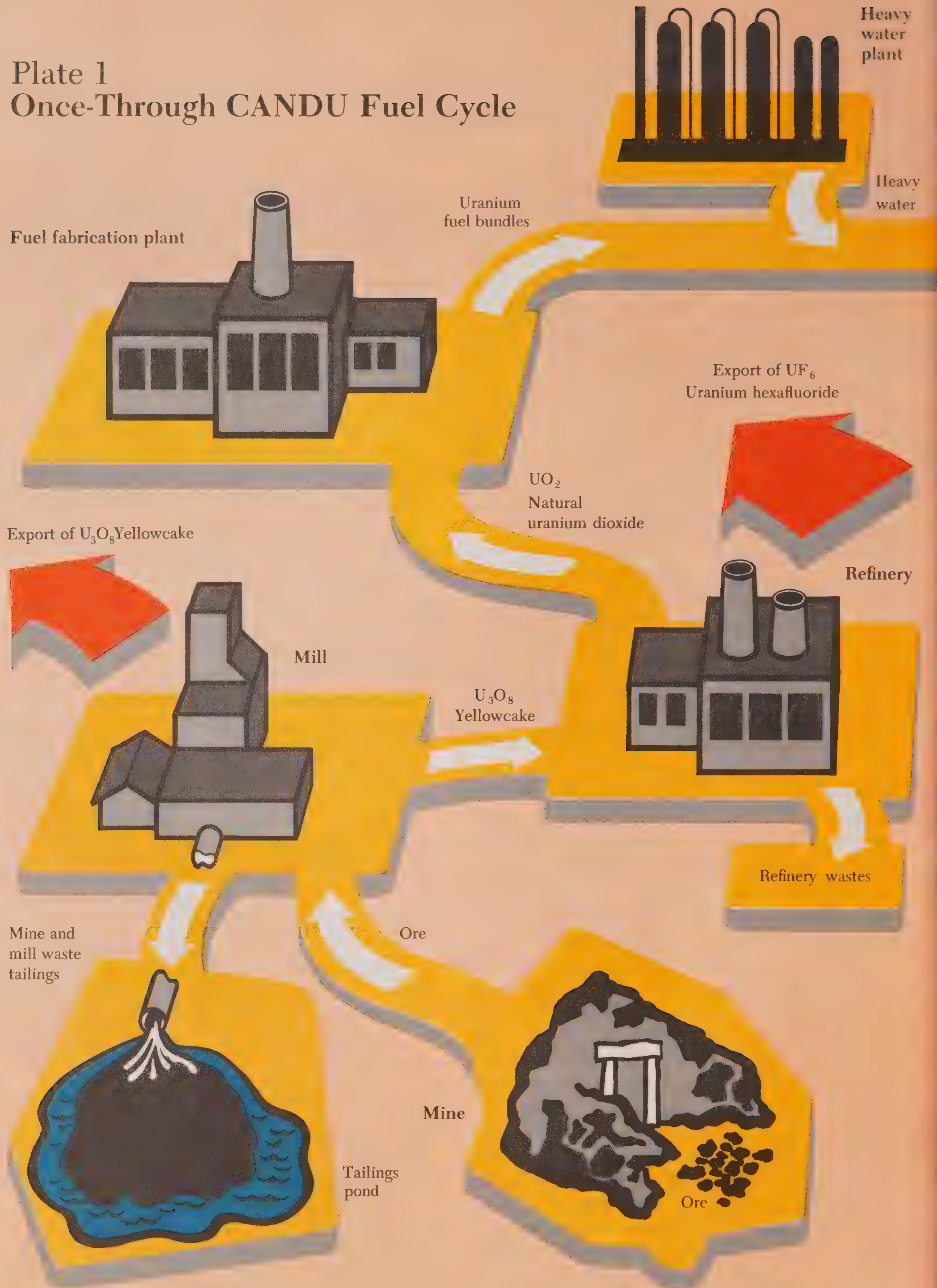
Even after 5-10 years storage in CANDU spent fuel storage bays, the fuel bundles remain highly radioactive and continue to generate heat. This means that special precautions would have to be taken to transport them to a reprocessing plant.[10] But the most hazardous operation in all advanced fuel cycles is probably the reprocessing operation itself. At an early stage it necessitates, for example, the dissolution of the spent fuel in nitric acid and hence all subsequent processes involve highly radioactive and corrosive liquids. Remote handling, of course, is essential. Compounding the difficulties is the fact that large amounts of spent fuel, perhaps several thousand tonnes per year, would have to be handled. Furthermore, the end-product is plutonium oxide, a highly toxic and radioactive substance which can be an energy source as well as material for nuclear weapons. Special precautions must be taken to ensure that a condition of "accidental criticality" does not occur since a critical mass of Pu-239 will spontaneously explode.

The reprocessing of spent fuels has been undertaken for upwards of 30 years in connection with

nuclear weapons programmes. Britain and France, in particular, also have many years of experience in reprocessing spent fuel from nuclear power stations. To date, no major accidents have occurred. Large and increasing quantities of plutonium-239 from these plants, albeit under very strict security arrangements, could possibly be diverted to unauthorized or malevolent use. Dr. Walter Marshall of the United Kingdom Atomic Energy Authority has advocated the use of fast breeder reactors to "burn" these inventories of plutonium, thereby making them unavailable for diversion to illicit use.

The following Colour Section is a pictorial "walk-through" of the CANDU Fuel Cycle, complemented by diagramatic illustrations of the stages at each phase.

Plate 1
Once-Through CANDU Fuel Cycle



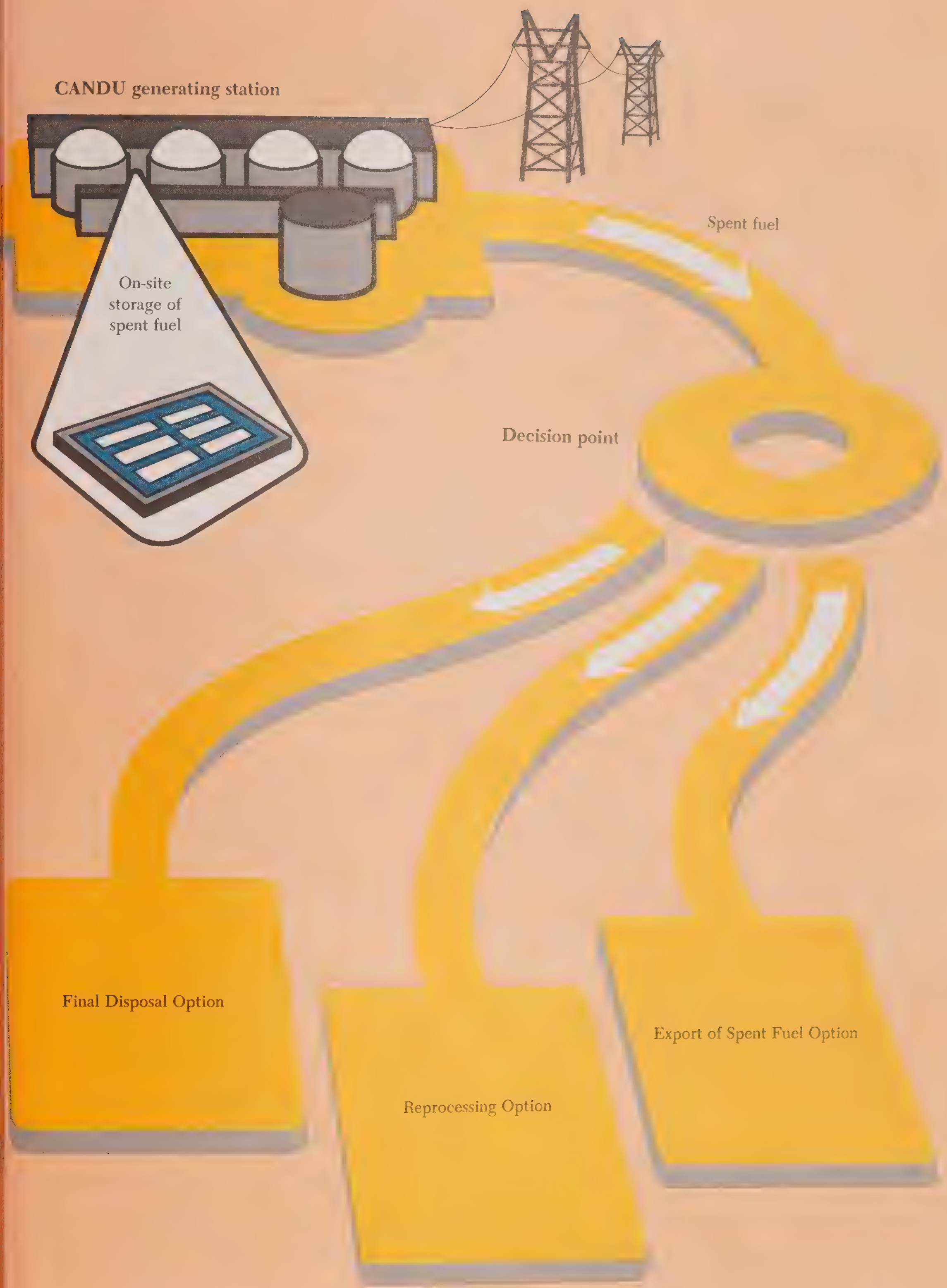

CANDU generating station
On-site
storage of
spent fuel
Spent fuel
Decision point
Final Disposal Option
Reproccssing Option
Export of Spent Fuel Option

Plate 2
From the Ore to the Fuel Bundle

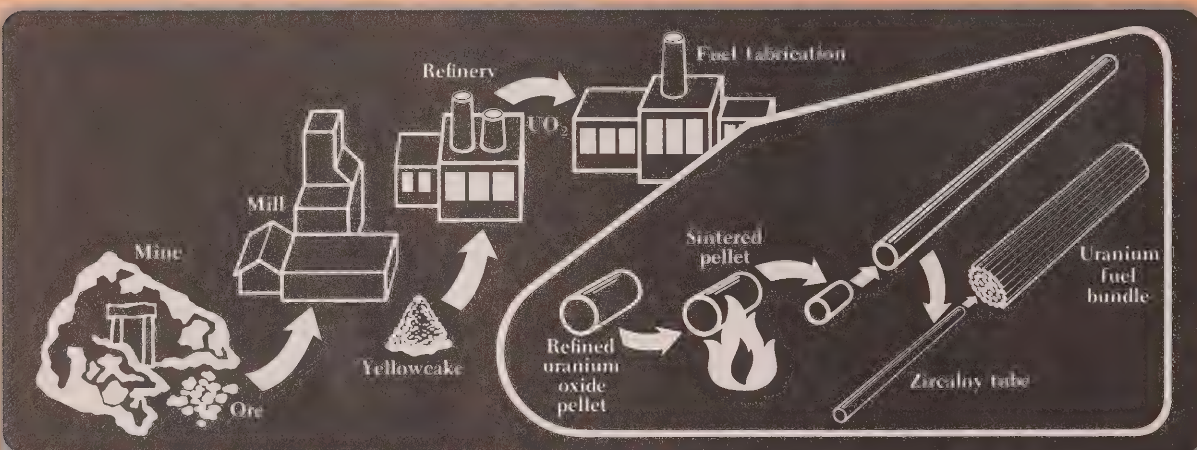
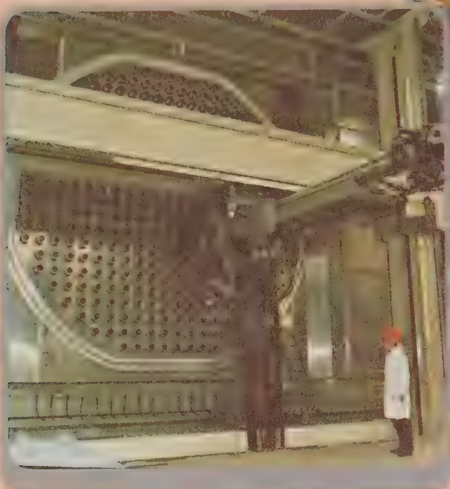
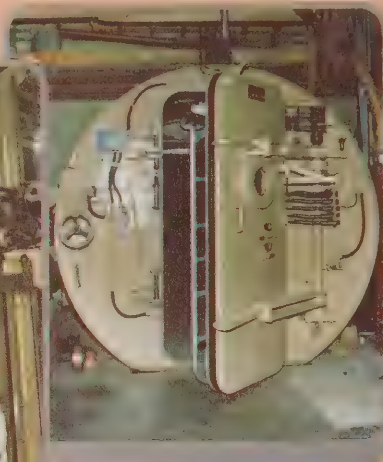
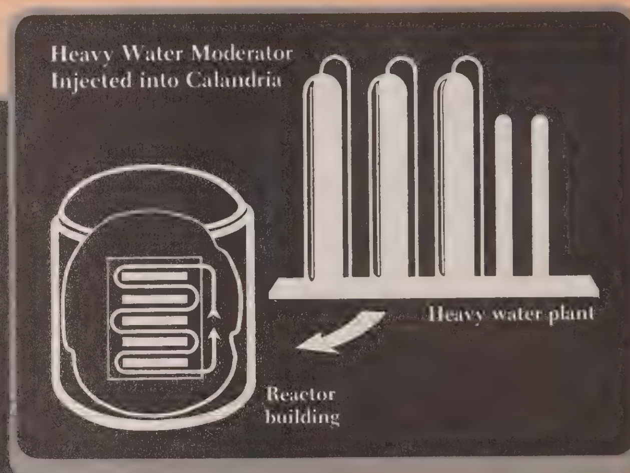


Plate 3
Building the CANDU Station

Plate 4
Fuelling and Operating a CANDU Reactor







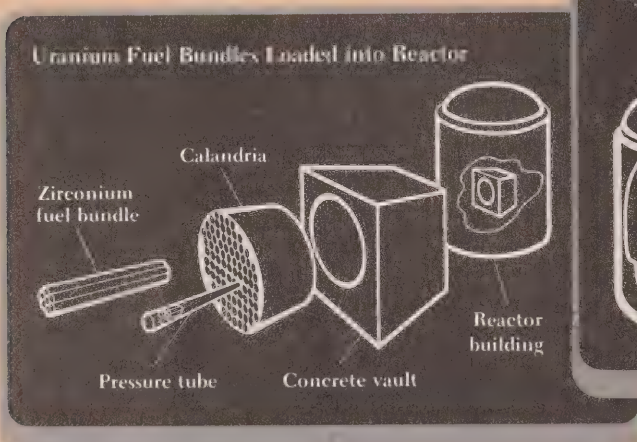


Plate 5
Electricity to the Consumer

Plate 6
Wastes from the CANDU Cycle

Plate 7
For All of Us

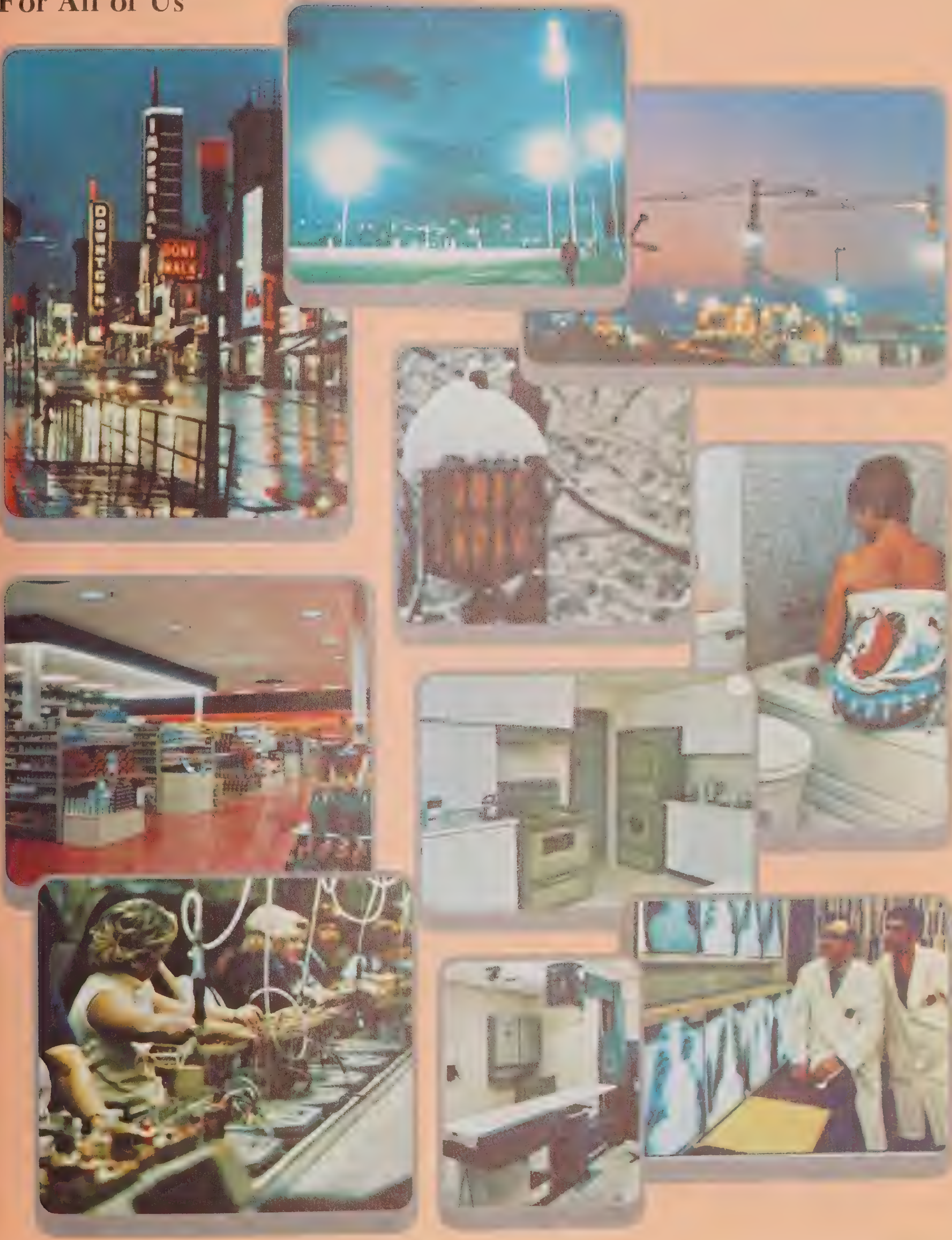


Figure 5.1 Global Distribution of Nuclear Power Stations

SOURCE Based on data from Nuclear News, various issues.

Chapter Five

The Nuclear Debate

THE development and commercial deployment of nuclear power technology in Canada and elsewhere has proceeded virtually unchallenged for three decades. The question of what role nuclear power would play in future energy strategies has, until recently, been taken for granted by governments and all but ignored by a public grown accustomed to having successive generations of increasingly complex and expensive technologies deployed in their midst.

Over the past five years, however, a growing international debate over the future role of nuclear power has emerged, especially in those countries where it appeared to offer the greatest promise of relief from dependence on imported petroleum — the United States, Japan, West Germany, France and Sweden to mention the most important examples. Formal inquiries and major studies have been conducted by respected organizations in the United States (the Ford-MITRE Report which heavily influenced President Carter's energy policy statement in April 1977), the United Kingdom (the Flowers Report) and Australia (the Ranger Uranium Environmental Inquiry). In recognition of the complex and far-reaching global nature of nuclear development and potential concomitant risks — such as the additional, legitimate access to the basic raw materials, equipment and knowledge essential to the manufacture of nuclear weapons which this technology may provide to many nations — President Carter initiated a two-year, multilateral study in 1977. This initiative — the International Nuclear Fuel Cycle Evaluation programme — includes representation from Canada and will seek to identify and evaluate technical and institutional strategies for the nuclear fuel cycle which offer reduced access to material suitable for use in nuclear weapons.

In Canada, the nuclear debate has emerged over the past two years as an increasingly significant public policy issue. Public attention has been focussed on some nuclear issues by sporadic and not always thoughtful media coverage of, for example:

- the health of uranium miners and recently, workers in the Eldorado Nuclear Limited refinery at Port Hope;
- the radioactive contamination of buildings in Port Hope from landfill which contained tailings from the Eldorado Nuclear Limited refinery;
- the reaction of Madoc residents when it was thought that their community may have been proposed as one possible site, deserving of further testing, for a nuclear waste repository;
- the controversy over the export of CANDU reactors to South Korea and Argentina;
- the Soviet nuclear-powered satellite which came down in the Northwest Territories; and
- the recent Denison-Preston uranium contract with Ontario Hydro.

A number of formal inquiries and studies at both the provincial and federal levels provide further evidence of a growing debate in Canada. At the federal level, a committee chaired by Dr. F. Kenneth Hare recently published its findings in a document entitled 'The Management of Canada's Nuclear Wastes'. The House of Commons Standing Committee on National Resources and Public Works has conducted public hearings on the recommendations of Dr. Hare's report. In Saskatchewan, Mr. Justice J.E. Bayda chaired the Cluff Lake Inquiry to examine a proposal to develop the rich

uranium deposits of Northern Saskatchewan; the Report of this inquiry was published in August 1978. The Ontario Legislative Assembly Select Committee on Ontario Hydro Affairs was recently asked to comment on a large uranium contract; it is addressing the wider issues of nuclear power in the near future.

Finally, this Commission has heard the views, concerns, fears, and hopes of many Ontarians. During the past nine months (September 1977 to April 1978) of our inquiry, the debate was focussed on nuclear power. This Interim Report reflects the importance which this aspect of the debate has assumed in our work.

Clearly, the "nuclear debate" must accommodate and cope with discussion of both highly technical and scientific matters as well as emotional concerns and fundamental anxieties. It is apparent that Hiroshima remains imprinted upon the collective unconscious, not the peaceful descendant of this military technology — the nuclear power plant. Moreover, the debate over the future role of nuclear power is ultimately a political debate — in the broadest sense of the word. If the creation of usable energy is seen, not as an end in itself, but rather as a means to achieve social goals (planned or otherwise), then value judgements are clearly implied by decisions about future energy policies. The nuclear debate we have conducted has therefore, justifiably, frequently centred on social, political, economic and ethical issues related to the broad outlines and well-being of future society. While it must be recognized that nuclear power does not have a monopoly on the pressing issues of the day, the deployment of nuclear power in Ontario and elsewhere poses a complex set of serious concerns different from those of other forms of power generation.

The evolution of the nuclear debate in Ontario, as elsewhere, has been characterized by an increasing polarization of views between the proponents of nuclear power and a small but growing and vocal opposition to the expanded use of nuclear energy. Spokesmen for the nuclear industry have sometimes left the impression that they regard critics of nuclear power as uninformed and irrational opponents of all technological and economic progress who seem to dream naively of a return to a simpler life. Alternatively, some critics of nuclear power have on occasion taken positions which have come close to suggesting that the nuclear industry is responsible for most, if not all, of society's current and future ills. While, for the most part, we have heard responsible, highly intelligent and sometimes eloquent arguments from both sides, the propensity for heated and emotional exchange is ever-present, resulting in a psychological climate in which a reconciliation of views has been extremely difficult. The Commission's hearings have, we hope, provided a much needed public forum to facilitate a frank and educational exchange of information, viewpoints and ideas.

In general and simple terms, the major arguments for and against a continuing and expanded commitment to nuclear-generated electricity in Ontario which the Commission has heard during the course of the nuclear debate are outlined below.

The Case for Nuclear Power

- The arguments for nuclear power rest on the assumption that the demand for electrical energy will continue to experience growth in the foreseeable future. Energy conservation and alternative, renewable energy technologies (solar, biomass, wind, etc.) will have a marginal and uncertain impact on this demand by the year 2000. An assured and reliable supply of electricity provides substantial economic and social benefits which would be at risk if shortfalls are allowed to develop in the supply of electrical energy.
- Oil and natural gas, which are not resources indigenous to Ontario, have important uses (chemical feed-stocks, liquid transport fuels) for which they should be increasingly reserved as their price escalates and supply depletes by substituting electricity wherever possible.
- Coal, with which Ontario is not well endowed, is the principal alternative to nuclear-generated electricity but has escalated rapidly in price and carries with it heavy environmental and health costs.
- Uranium is indigenous to Ontario and is available in significant quantities elsewhere in Canada, thereby minimizing the province's dependence on

uncertain and increasingly expensive imports and maximizing our potential for self-reliance.

• The CANDU reactor technology developed independently by Canada over the past twenty-five years represents an unparallelled achievement in an extremely competitive high technology field. It is a proven technology which is available now.

• The CANDU reactor burns natural uranium which not only is available from within our own frontiers but obviates the problems associated with the acquisition of uranium enrichment services, a costly, complex and sensitive (from a proliferation point of view) technology available to few countries today yet necessary for all current generation non-CANDU light water reactors. Furthermore, CANDU reactors consume uranium more efficiently than any other first generation reactor available and therefore help to conserve this non-renewable resource.

• All human undertakings inevitably involve some risk to individuals and society as a whole. The safety of CANDU, and indeed nuclear power stations of all types, has been demonstrated. The safety standards and record of the nuclear industry are unequalled and provide a model for other industries. Nuclear power, therefore, represents a risk to society which is vanishingly small, particularly when compared to the risks to which we are already, often voluntarily, subjected.

• Nuclear power is environmentally more benign when compared with currently available alternatives, especially coal. Radioactive emissions from nuclear plants during routine operations are negligible when compared to natural background radiation to which we are all subjected or to the radiation dose which the average person receives from medical X-rays. Although the wastes created by nuclear-generated electricity are highly radioactive for very long periods of time, they are much smaller in volume and can be more easily contained and isolated from the environment than the by-products of coal-fired generation.

• CANDU generated electricity has proven to be highly reliable and is independent of uncontrollable factors such as weather.

• Based on life-cycle costs, nuclear-generated electricity is significantly less expensive than currently available alternatives such as coal. The nuclear industry anticipates that the cost advantage which nuclear energy now enjoys will tend to increase with time.

• A Canadian nuclear industry, based largely in Ontario, with the capability to fabricate and supply 80 per cent of the equipment and material required for CANDU plants, has been put in place over the past two decades. This industry employs 30,000 people, many of them highly skilled professionals and technicians. If an orderly domestic market of sufficient volume for CANDU plants is forthcoming, the future employment and investment potential offered by nuclear power is impressive.

• Although there is no economic incentive to recycle and reprocess spent fuel from current, highly efficient, once-through natural uranium burning CANDU reactors, CANDU can be adapted to other fuel cycles based on plutonium or thorium. This flexibility could greatly extend the life and viability of both the CANDU system and finite uranium supplies, thereby providing a Canadian alternative to the fast breeder reactor.

The Case Against Nuclear Power

• The critics of nuclear power are confident that an effective programme of energy conservation and efficiency improvement is possible and could significantly reduce the growth rate for electricity without altering existing lifestyles and living standards, thereby making nuclear power unnecessary. They argue that an energy conservation programme would be cheaper, faster and less environmentally disruptive while creating more jobs, where they are needed, than by bringing nuclear generating capacity into being. Such an approach would buy time to re-evaluate energy supply strategies leading in the long run to a sustainable, resilient energy system based on indigenous, renewable energy technologies (solar, biomass, wind, etc.) which can be more appropriately and efficiently matched to the end-uses for which energy is needed.

• The safety of nuclear power stations, especially CANDU stations with their limited operational experience on a commercial scale, has not been proven beyond reasonable doubt. The health

and environmental consequences of a major accident at a nuclear plant could be both long-lived and catastrophic. The probability of such events is higher than the low risk levels which the nuclear industry has publicized.

- Public health and the health of workers across the entire nuclear fuel cycle — mining, milling, refining, fuel fabrication, plant operations, spent fuel management, and decommissioning — may be at risk due to chronic exposure to low-level radiation, the aggregated effects of which may not be detectable for many years.
- The mining and milling of uranium ore produces very large volumes of long-lived, low-level radioactive tailings which have leached into waterways in the vicinity of Elliot Lake, Ontario, thereby posing serious health and environmental problems which have yet to be adequately addressed.
- No method for the safe and permanent disposal of toxic and long-lived high-level radioactive nuclear wastes has been demonstrated. These wastes must be isolated from the environment and people for periods of time longer than the recorded history of human civilization and may therefore present a threat to future generations who will not have received any of the benefits of nuclear-generated electricity.
- The current cost figures for nuclear-generated electricity do not reflect the true costs because of various forms of government subsidization and hidden or externalized costs which society as a whole will pay. Nuclear power is also extremely capital-intensive, a situation which will result in fewer jobs per dollar invested than any alternative. Therefore, a heavy commitment to nuclear power will limit the availability of capital both for other social uses and for the development of alternative energy systems whose costs and benefits seem more sensible and sustainable.
- Nuclear power is a centralized, highly capital-intensive and complex technology which few people understand. It is a 'hard' technology requiring very long lead-times, highly sophisticated controls, extensive planning and regulation and unending vigilance to ensure safety. It is therefore a technology which demands and tends to increase further the centralization of society, thereby eroding further our potential for diversity, resilience, self-reliance and adaptivity.
- Nuclear power is based on an uncritical and unimaginative extrapolation of historical trends into the future. The lengthy lead-times required to deploy nuclear stations provide little flexibility to cope with future social, economic and political uncertainties.
- If a major commitment is made to expand nuclear power in Ontario, the reprocessing of spent fuel to extract plutonium and the deployment of second-generation advanced fuel cycle technologies will become inevitable because of the finite nature of uranium resources. The massive human and financial resources which will have been committed over the next two or three decades will provide an added and perhaps irresistible momentum. These second-generation nuclear technologies will dramatically escalate the safety, environmental and proliferation risks associated with nuclear power.
- Nuclear power will lead to greater local and international tension and instability by making the raw materials and basic technology required for nuclear weapons more widely available, by providing further potential targets to terrorists, the inevitable response to which will negatively affect our civil liberties, and by forcing competition for an increasingly strategic but finite raw material — this time uranium rather than oil.
- Nuclear power should be considered a technology of last resort and the option of phasing out of this technology before it becomes irreversibly established should be preserved. A temporary moratorium on further expansion of nuclear energy should be immediately adopted while an extensive education programme is undertaken to better inform the public as to the full range of implications which would accompany a large future commitment to nuclear power in Ontario. Measures to ensure the continued viability of the nuclear industry during a temporary moratorium should be developed. The moratorium should be accompanied by serious programmes of energy conservation and renewable energy development.

As is generally the case in the course of human

affairs, particularly when issues are of such importance that they are intensely and frequently emotionally debated, the truth may well lie somewhere between these two, seemingly polar, positions. When an issue is, at once, as complex and as crucial as is the case with nuclear power, then a responsible dialogue and extensive, wide-ranging public participation are fundamentally important if wise and just decisions are to be made. This is especially important at this point in our history, when public trust and confidence in traditional institutions and government, in Ontario and all western industrial democracies, may be decreasing.

The Ontario public is, in general, uninformed and perhaps even cynically uninterested in energy problems. This is even more the case with nuclear power, where the level of knowledge and understanding is often minimal at best. It is difficult and perhaps unproductive to assign responsibility for this state of affairs at a time when major decisions with far-reaching social, economic and political consequences with which all Ontarians will have to cope are pending.

Two requirements are clear to us. First, new and imaginative ways must be found to inform and involve the public in these important issues. To do otherwise will risk unexpected and time-consuming resistance to future projects when the local implications become obvious to affected communities who may perceive a different relationship between the risks incurred and the benefits to be derived than the planners did. Amongst the ideas that this Commission has heard which deserve further consideration are: a Science Court, with public as well as multi-disciplinary representation from such diverse areas as ethics, sociology and the sciences; a citizens' Energy Advisory Committee; community, storefront Energy Information Centres; new energy-oriented courses in the school system, particularly the elementary schools; a serious and ongoing commitment by all media forms to bring energy issues before the public in an objective and responsible way.

Secondly, we have concluded that if an informed and reasonably sophisticated public involvement in the energy debate is to be achieved, then greater and freer public access to information is essential. This is particularly important in the case of nuclear power, where, perhaps because of the historical links of civilian nuclear energy to military weapons programmes, an aura of secrecy still shrouds the contemporary nuclear industry. This aura, together with the quite natural tendency of any industry to promote its products, has often led to public suspicion that unfavourable data are withheld and that the information made available by the nuclear industry, which often intimidates the layman because of its technical complexity, is not always objective. If these suspicions are to be mitigated and if public trust and acceptance of nuclear power are to be maintained, then the nuclear industry must continue to become more open to public scrutiny.

Figure 6.1 Energy Cycle

Chapter Six

Health, Environmental and Safety Concerns

THIS Chapter deals with the impact of the nuclear fuel cycle on people and on what is loosely described as the environment. Man and his environment are complementary. Man changes the environment, and slowly, very slowly, the environment changes man. Together, they constitute the biosphere — the thin shell associated with the earth's surface and the atmosphere in which all life resides. Industrial developments, and by no means least the generation of electricity, interfere with nature's long established ecological balances and cause irreversible and usually undesirable changes. Pollution is a major manifestation of ecological imbalance. Furthermore, because of nature's extremely long evolutionary time-constants, man has changed little, anatomically and physiologically, during the past fifty thousand years. By the same token, he is slow to adapt to environmental changes. Nuclear power, which has potential for much good, constitutes a major environmental challenge — to what extent can it be contained? How safe is the fuel cycle? The major threat associated with the nuclear fuel cycle to health and the environment arises from receiving excessive doses of radiation. (An elementary scientific introduction and a summary of radiation standards are presented in Annex D.)

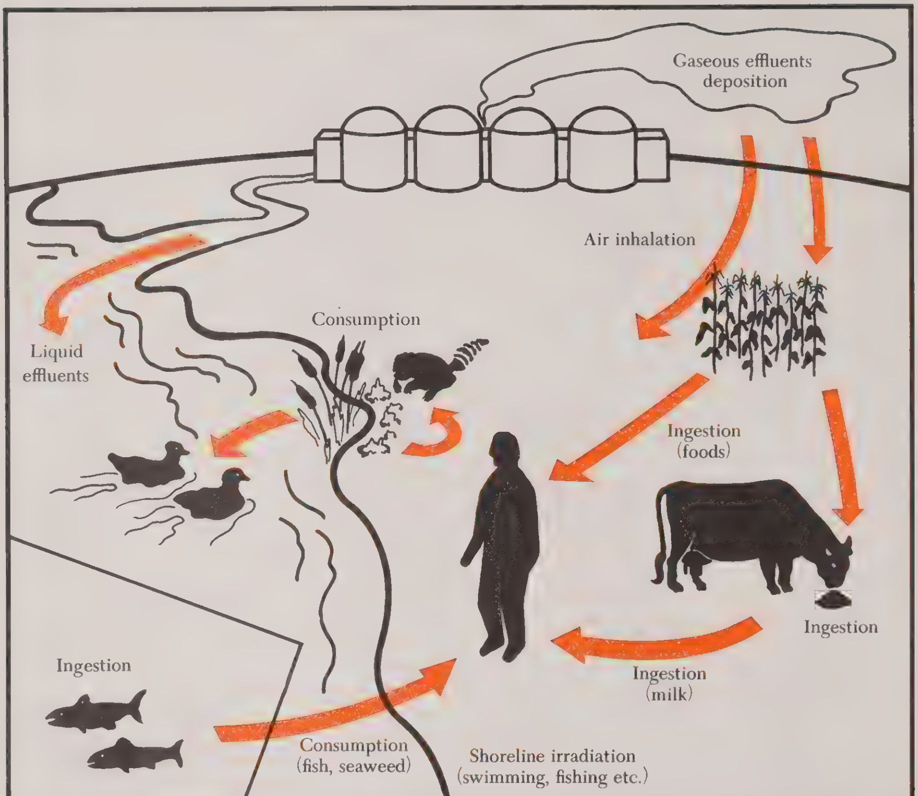
Low-, intermediate-, and high-level radiation are present in all phases of the nuclear fuel cycle. However, the most concentrated and lethal radiation is produced in the core of the reactor itself. The energy released by the fission of uranium is both thermal, which we contrive to capture, and high energy radiation in the form of neutrons, alpha-particles (α), beta-particles (β) and gamma-rays (γ), which we contrive to contain. This radiation emanates from radioactive isotopes which are not only produced in the reactor core but are also important constituents of uranium mill tailings and, of increasing concern, spent nuclear fuels. The pathways by which these radioactive substances, as well as toxic chemicals, can be transmitted back to man through water movements and through a multiplicity of food chains are extremely complex. Moreover, these substances become more and more concentrated as higher and higher levels in the food chains are reached. In the case of many of them, man is at the apex (see Figure 6-2). A basic understanding of how radiation affects man is obviously important.

Biological Effects of Radiation

Since its creation, four to five billion years ago, the earth, itself a source of radioactivity, has been continually bombarded by radiation in the form of cosmic rays and x-rays from outer space, as well as ultraviolet radiation from the sun. On the one hand this radiation has been essential to ensure the requisite variety of nature, and the evolution of man, but on the other hand, it can be harmful — long exposure of the body to solar radiation can cause cancer of the skin.

Although the mechanisms whereby radiation changes cellular structure, even to the extent of killing the cell, and the processes involved in the subsequent replication of damaged cells, are not fully understood, we know a great deal about the effects of radiation on human health. There are three classes of radiation-induced disease. Acute "radiation sickness" is associated with exposure to massive doses of radiation, e.g. many of the atomic bomb victims died within a few days of exposure.

Figure 6.2 Pathways for Radioactive Substances



Emissions from the Pickering Generating Station*

	1971	1972	1973	1974	1975	1976
Gaseous releases						
Noble gases	.017	.022	.018	.002	.0022	.0012
Tritium	.001	.0014	.0033	.0024	.002	.0023
Iodine 131	.013	.0063	.00025	.0002	.000045	.000072
Liquid releases						
Tritium	.0001	.00016	.0004	.0009	.00064	.00036

*Expressed as a fraction of derived emmission limit.

Fortunately, this is a very rare class. Radiation effects which may take many years (the latency period) to affect human health, through causing cancer, are referred to as the somatic effects; these effects are not transmitted to offspring. The third class, the genetic effects, arises because radiation can cause genetic damage which may become manifest in the children and grandchildren of an exposed person. Except in the event of a major nuclear accident, somatic and genetic effects can be controlled by limiting the exposure for individuals and by ensuring the minimization of the total radiation release to which the entire population is exposed.

One of the most controversial issues relating to the nuclear fuel cycle is the effect of low levels of radiation on health. Very large samples are necessary to provide significant results, and it is not surprising that, because the period between irradiation and the detection of cancer may be in the order of twenty years, experimentation is extremely difficult. Although there is a considerable amount of experimental evidence relating radiation exposure and the induction of malignancy in animals, the only evidence concerning humans is based on groups who have been subjected to very high levels of radiation — in particular, the Japanese atomic bomb survivors, and several thousand patients treated for spinal arthritis by massive doses of x-rays. Data from these groups have been used to estimate the effect of low-level radiation by assuming a linear relationship between radiation and induced cancer or leukemia. The so-called "linear hypothesis", in simple terms, assumes that if a given radiation dose induces a certain number of malignancies, then a fraction of that dose will induce a proportionate number of cases. The once generally accepted "threshold hypothesis", which assumed that there was a threshold level of aggregated radiation below which neither somatic nor genetic disease would be induced, appears to have been superseded.

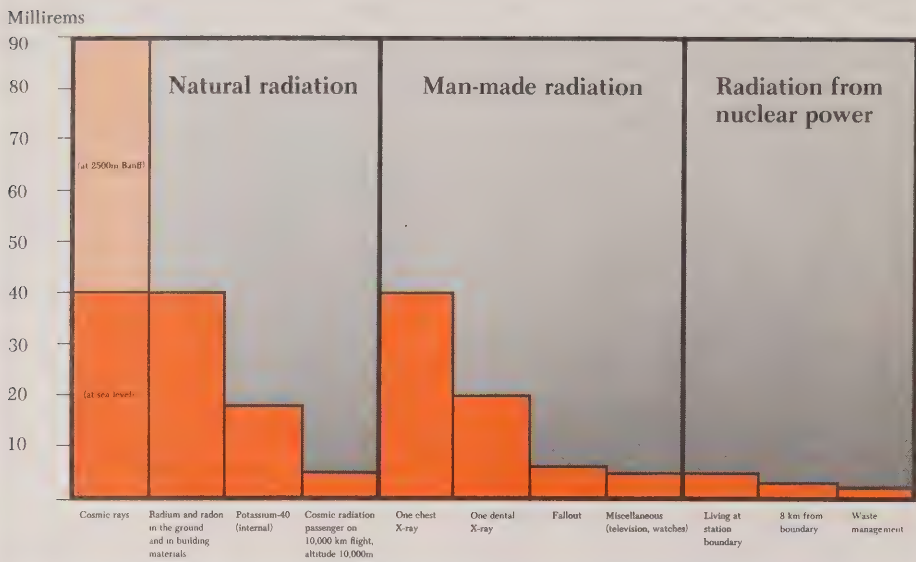
The International Commission on Radiological Protection[1] (ICRP), on the basis of the existing evidence, has recommended maximum limits for human exposure to radiation. (These are given in Annex D.) Most nuclear regulatory bodies, including Canada's Atomic Energy Control Board (AECB), have based their radiation dose limits for humans on the ICRP recommended levels. In addition to setting exposure limits to the whole body, the gonads and other sensitive organs, the AECB has also established limits on the "genetic dose to the whole population" — which should be kept below 5 rems per generation (i.e. the dose aggregated over a period of thirty years). It is particularly important to note that expert opinions differ as to the risk from exposure at the levels which have been established. However, it is generally agreed that the exposure of the general public to radiation caused directly by nuclear power stations is only a small percentage (about 1 per cent) of the recommended maximum levels. For workers in the nuclear industry the maximum permissible doses are at a level 10 times those applicable to the general public. The limits for workers have been rigidly enforced through individual monitoring of radiation doses.[2]

Because each one of us is exposed to between 100 and 150 millirems per year of naturally occurring radiation, it has been argued that, since the radioactive discharge, under normal operating conditions from, say, Pickering G.S. as monitored at the plant perimeter is only 5 millirems/year, this is virtually negligible. Indeed, it has been pointed out that 5 mrem/year is the additional dose received by a person flying from Canada to Europe once a year, or a person living at an altitude of about 3,000 feet above sea level. On the other hand, some critics of nuclear power have suggested that the linear hypothesis, far from being conservative, may in fact underestimate the health hazards of additional radiation doses, however small.

The emissions from the Pickering station, the average radiation doses from various sources, and the dose limits for various organs are given in Figures 6-2 and 6-3 and Annex D respectively.

Notwithstanding the established dose limits, it is clear that exposure of people to radiation should be kept as low as practicable. Noteworthy is the fact that there is need for more conservative use of diagnostic radiology in particular — we cannot do anything about background radiation, but the second largest contributor to annual radiation dose is medical x-rays for diagnostic purposes.

Figure 6.3 Average Radiation Doses from Various Sources



SOURCE Atomic Energy Canada Limited

Fuel Production: Health and Environmental Concerns

As shown in Plates 1 and 2, in the Colour Section, the production of nuclear fuel (the "front-end" of the CANDU fuel cycle) comprises the mining and milling of uranium ores to produce uranium oxide (U_3O_8), the disposal of the mill tailings, the refining and fabrication of the uranium oxide into pellets, and subsequent assembly into fuel bundles. The technical processes involved in these operations were outlined in Chapter 4.

The health and safety of workers in the Elliot Lake uranium mines was investigated by the Royal Commission on the Health and Safety of Workers in Mines (the Ham Commission[3]). The Commission reported on the hazards associated with uranium mining which may induce lung cancer:

- inhalation of radon gas and growth of its short lived products (or radon daughters) in the mine atmosphere or in other enclosed areas (see Table 6-1 for a listing of radon and its daughters).
- ingestion and inhalation of uranium concentrates by operators in the precipitation, filtering, drying and packing areas in the mill;
- external radiation in the neighbourhood of very high grade ores;
- radiation due to thorium (four times as abundant as uranium in the rock of the Canadian Shield) as a byproduct of milling or from reworked tailings.

We agree with the Ham Commission that ways must be found to reduce these hazards, and we are encouraged by the fact that legislation incorporating many of the Commission's recommendations seems likely to be introduced during the next session of the Ontario Legislature.

Since 1954, when uranium mining began in the Elliot Lake region, there has been serious environmental contamination in the immediate vicinity of the mines resulting from the leaching of radioactive substances, especially radium-226, and from highly acidic tailings. The mill tailings are dumped near the mill and have approximately the same bulk as the original ore. At present, for example, there are approximately 75 million tonnes of tailings in the Elliot Lake vicinity. Plate 6, in the Colour Section, showing the mill tailings from one mine, illustrates the problem quite dramatically. The safe disposal of these tailings constitutes a major problem. Several lakes and streams have been badly contaminated — notably the Serpent River. One of the major problems has been that of containing the tailings so that the radium, which is readily dissolved by water, is prevented from entering streams; the problem of high acid levels is being handled chemically.

Beginning in November, 1976, the Ontario Environmental Assessment Board (EAB) has conducted a series of public hearings in Elliot Lake with respect to the expansion plans of the uranium mining companies. In connection with these, consultants have undertaken a comprehensive environmental impact assessment which is at present in the hands of the Board. We are aware of major environmental implications of the mill tailings, and we note with approval that the responsible provincial authority, the EAB, is undertaking this public inquiry on such an important subject. An indepth study, recently undertaken on behalf of the American Physical Society[4], has concluded that:

> The parts of the fuel cycle that contribute the most to public radiation exposure are fuel reprocessing, uranium mining and milling.

Because no fuel reprocessing is currently taking place in Ontario, the implication is that the uranium mining and milling component contributes more to public radiation exposure than the remainder of the CANDU fuel cycle, including the management of spent fuel.

As the uranium mining industry expands, it is foreseeable that several hundred million tonnes of mill tailings will be left behind in the tailings ponds by the year 2000. This will constitute, as it does at present, an increasing health and environmental problem in the Elliot Lake region.

Another important dimension of the mill tailings problem relates to the question of what happens to the tailing ponds when the mining companies cease operations — that is when the ore deposits have reached uneconomic levels? Although there are legislative proposals aimed at establishing sinking funds to finance the mine decommissioning phase, there are no obvious technological solutions in sight. In view of the conclusions of the American Physical Society study

Table 6.1 Radon and its Daughters

Isotope	Half-life (Months)	Principal radiation
Radon-222	0.1275	*alpha* α
Polonium-218	3.05	*alpha* α
Lead-214	26.8	*beta, gamma* β, γ
Bismuth-214	19.7	*beta, gamma* β, γ
Polonium-214	6.3×10^{-11}	*alpha* α

that the mill tailings problem is probably more difficult to handle than the ultimate disposal of high-level radioactive wastes, partly because of the extremely large volumes involved, it is clear that urgent consideration must be given to it.

We have concluded that an independent review committee, consisting of internationally recognized ecologists, and reporting to the Atomic Energy Control Board and the Ontario Environmental Assessment Board, should be established to study the mill tailings problem in depth. At about two or three year intervals the nuclear power programme, and in particular the uranium mining and milling part of the fuel cycle, should be assessed in the light of the findings of this review committee.

The health and environmental implications of other aspects of the front-end of the fuel cycle — such as the transportation of uranium concentrates, fuel elements and bundles — as well as the refining processes are not considered to be as serious environmentally as the mill tailings problem. Nevertheless, the health and environmental problems of the Port Hope refinery (Eldorado Nuclear Limited), although comparable to that of other chemical processing plants, involve the handling and subsequent disposal of radioactive materials. Consequently, the refinery is licensed by the AECB and operations are monitored by the Ontario Ministries of Labour and of the Environment. It is noteworthy, however, that the environmental impact of a second proposed refinery comes under the jurisdiction of Environment Canada's Environmental Assessment Review Process, which involves public hearings.

It appears to be generally accepted by governments and the public that the waste disposal problems which arose at Port Hope will ensure a high level of vigilance on the part of Eldorado Nuclear Limited and of the AECB. Nor should it pass unnoticed that it was largely the initiative of public interest groups which brought the problem to light and subsequently facilitated the cleaning-up operations.

The Health and Environmental Impacts of a Major CANDU Reactor Accident

In subsequent sections we will consider the steps being taken to minimize the possibility of major reactor accidents. First, however, it may not be out of place to consider the nature of the threat in the highly improbable event of such an accident taking place.

All operating nuclear reactors accumulate in their cores, as we have indicated, a large quantity of radioactive material. For the most part this is made up of the fission products, many of which are short lived and usually very radioactive, and the actinides (e.g. plutonium-239) which are very long lived and highly toxic substances (see Tables 6-2 and 6-3).

By definition, a major reactor accident would lead to the severe overheating, and subsequent melting, of the nuclear fuel, which would give rise to a substantial quantity of radioactive material escaping, after breaching several formidable barriers, into the environment. The major health and environmental threat would be due to the escape of the fission products to the atmosphere. The most important of these are caesium, ruthenium, tellurium and the fission gases, iodine, krypton and xenon. Although no such major accident has ever occurred anywhere on earth,[5] it is assumed that if a substantial quantity of radioactivity were to be released to the atmosphere, the radioactivity would collect in a "cloud" and would be carried down wind. The closer to the reactor building (or within the building), the greater the probability of an individual's being exposed to intense radiation. At distances of two or three kilometres, depending on wind velocity, the cloud would begin to disperse (the dispersal zone could extend to distances of several hundred kilometres) and radioactive materials would be deposited on the ground. In consequence, both prompt and latent cancers would be produced.

It is generally agreed that the greatest threat to health in the event of a major reactor accident is the considerable quantity of the radio-isotope iodine-131 (with a specific activity of 1.2×10^5 curies/g, and a half-life of 8.2 days) which would be released to the atmosphere.

It is well known also that I-131, after ingestion or inhalation, concentrates in the thyroid gland and may cause, after a latency period, thyroid cancer.

Table 6.2 Important Fission Products in One Kilogram of CANDU Spent Fuel

Radioisotope	Radioactive half-life (Days)	Significant radiations	Specific activity (Curies/gram)
Iodine-131	8.1	*beta, gamma* β, γ	1.2×10^5
Xenon-133	5.3	*beta, gamma* β, γ	1.9×10^5
Krypton-85	3,944.0	*beta, gamma* β, γ	391
Ruthenium-106	368.0	*beta* β	3.35×10^3
Tellurium-127	109.0	*beta, gamma* β, γ	9.43×10^3
Caesium-137	10,957.0	*beta, gamma* β, γ	87

Table 6.3 Actinide Components in One Kilogram of CANDU Spent Fuel

Actinide	Radioactive half-life (Years)	Significant radiations	Specific activity (Curies per gram)	Mass (grams)
Plutonium-239*	24,390	*alpha* α	$6.1 \times 10^{[illegible]}$	2.7
Plutonium-241*	14	*beta* β	112	
Plutonium-238	87	*alpha* α	17	1.1
Plutonium-240	6,660	*alpha* α	$2.3 \times 10^{[illegible]}$	
Plutonium-242	387,000	*alpha* α	$1.0 \times 10^{[illegible]}$	
Americium-241	458	*alpha, gamma* α, γ	3.2	1.2
Americium-242	0.0018	*beta, gamma* β, γ	$8.2 \times 10^{[illegible]}$	
Americium-243	8,000	*alpha* α	$1.9 \times 10^{[illegible]}$	
Curium-242	0.51	*alpha*, neutron α	3320	
Curium-243	32	*alpha* α	47	
Curium-244	17.6	*alpha*, neutron α	83	

*Fissionable actinide

The threat to children in such circumstances is particularly serious because the I-131 could be ingested in the form of contaminated milk. A measure which has been proposed to minimize the effect of I-131 is the administration of an appropriate dose of potassium iodate within an hour of the ingestion of the radioactive isotope. Because of its half-life of about 8 days, I-131 remains highly radioactive for a few weeks. Subsequently, the major contributor to the radiation field is caesium-134 with a half-life of two years. The radioactivity arising from this isotope would persist for many years.

Apart from the direct radiation to which individuals might be exposed in consequence of the released radioactivity, there would also be a threat to the public in the immediate vicinity of the affected nuclear power station, from radioactively contaminated food and water. The emergency measures which would be necessary in the event of such a major accident would vary with the circumstances. Immediate evacuation of people living in the vicinity, and down wind, of the station might be necessary. Furthermore, the long term hazards, mentioned previously, would necessitate the isolation of contaminated food and water, and local decontamination procedures and the evacuation of people from heavily contaminated areas might be essential. The existing contingency plans are discussed in a later section.

Safety of the CANDU Reactor

When we talk about the safety of a nuclear reactor, we are referring essentially to how effectively the fantastic amount of radioactivity contained in the reactor core can be prevented from escaping into the ground and atmosphere in the event of major malfunctions. Clearly, if a major release of this accumulated radioactivity occurred, as discussed in the previous section, the consequences would be extremely serious and could involve several thousand immediate fatalities and many more delayed fatalities. This is the major issue which we address in this section.

An international authority on nuclear reactor safety, F.R. Farmer, has stated that:

> It is in the nature of low probability events, of the type considered, that it is impossible to prove that accidents cannot occur. In general we can only provide evidence to increase conviction in the validity of the hypotheses and accident models and in better understanding of the nature of accidents, their consequences and probabilities.

The safety of all nuclear reactors is predicated on "defence in depth", which involves:

- meticulous engineering design and construction aimed at minimizing the probability of accidents. This necessitates high quality materials, rigorous inspection during manufacture, the testing of components and systems, and finally comprehensive in-service inspection and testing;
- high reliability control, regulating and safety systems. The design of these systems is based, as much as possible, on the "fail-safe" concept;
- the ultimate level of defence, which involves the containment systems, minimizes the risk to plant workers and to the public in the event of a major accident.

Canada has played a significant role in the development of methods for assessing risks associated with the operation of nuclear reactors as well as for in-service testing. Noteworthy, during the 1950s, was the work of E. Siddall[6] and G.C. Laurence.[7] The former estimated the comparative risks of nuclear power and other industrial processes, based on the *a priori* assumption that nuclear power plants should be five times safer than coal-fired plants. Siddall's work was subsequently extended by Laurence, who established the risk levels associated with large releases of radioactivity. The achievement of low levels of risk, Laurence argued, should be based on the concept of separating the three basic reactor systems — the process systems (the primary heat transport, regulating and electrical systems), the safety systems (the shutdown and the emergency core cooling systems) and the containment systems (the reactor and vacuum buildings). This concept is the basis of CANDU reactor safety philosophy.

The absolute safety of any industrial process or human activity, including the generation of electricity cannot be assured. However, in the case of the CANDU reactor, we believe that the likelihood of a major accident occurring is extremely small.

Barriers to the Release of Radioactivity

To protect the public from potential radioactive releases, resulting from major accidents, the CANDU reactor incorporates a variety of physical barriers. The first barrier is the ceramic uranium oxide (UO_2) fuel pellet itself. Most of the radioactive fission products are bound within the UO_2, and can escape only if the fuel fails. The subsequent barriers include the zirconium fuel sheaths of the fuel bundles, the pressure tubes, the heavy water coolant and moderator, the steel calandria, and, in the case of the Bruce reactors and all future reactors, a steel shield tank filled with light water, which surrounds the whole calandria. Furthermore, the complete reactor assembly is located inside a thick, steel-reinforced, pre-stressed concrete structure — the reactor or containment building. (See Plate 4 in the Colour Section.) CANDU plants also have a separate vacuum building capable of containing gaseous emissions during accidents. Finally, the exclusion zone prohibits permanent habitation within one kilometre of the reactor building.

CANDU Safety Systems and Performance

The power level of a nuclear reactor is determined by the number of neutrons in the reactor core. This number can be controlled by inserting, or withdrawing, "control rods" which contain neutron-absorbing material (e.g. boron). The positioning of these rods is carried out automatically and involves a comprehensive system of instrumentation for monitoring various reactor parameters. The power level and the neutron flux configuration for each reactor are controlled by two independent digital computers.[8] A fault in one computer results in the automatic transfer of control to the other, while simultaneous failure of both computers results in reactor shutdown, as described below.

If operating limits are exceeded, e.g. in an emergency situation, the reactor must be shut down. In this case the nuclear fission reaction must be stopped very rapidly by inserting neutron-absorbing material. Several methods are available, all of which operate on fail-safe principles. The shutdown techniques used in Pickering A reactors involve, first, the release of a set of gravity and spring actuated shutdown rods, and secondly, the dumping of the heavy water moderator: these are essentially non-independent systems.[9] In addition to utilizing shutdown rods, Bruce reactors (and subsequent reactors) can also be shut down independently by "poisoning" the heavy water moderator (i.e. by inserting neutron-absorbing materials).

But even when the nuclear fission reaction is stopped, heat generation continues in the reactor core — although at a lower level and declining rate — and it is necessary to remove this heat as rapidly as possible. Accordingly, the major systems upon which reactor safety is predicated are the shutdown system (or systems), the emergency core coolant system and the containment system.

To date the most comprehensive study of nuclear reactor safety was undertaken for the United States Nuclear Regulatory Commission. It was directed by Dr. Norman C. Rasmussen, and the findings have been published in the widely cited report *WASH-1400*.[10] The study was based essentially on the identification of reactor components and the probabilities of their failure. (Note that the Canadian approach to reactor safety is predicated also on a probability approach, though less comprehensive.) In developing his model, Rasmussen identified key component failures, poor maintenance, operator errors, natural hazards and other possible causes of malfunction. The model simulated radioactive releases resulting from a range of accidents, and determined the associated public risks. The basic methodology was "fault-tree analysis", a technique that was developed originally in Britain in connection with the safety of aircraft and was subsequently used extensively by the National Aeronautics and Space Administration (NASA) in connection with safety aspects of the United States space programme. Although the conclusions of the Rasmussen study are by no means accepted universally, both pro- and anti-nuclear oriented scientists have recognized the value of the study as an important approach to assessing the safety of nuclear reactors.

Classification and Discussion of Potential Major Reactor Accidents

A single failure accident is defined as failure in any

one of the process systems — examples are the rupture of a pipe in the primary heat transport (i.e. cooling) system; the failure of a pump in the same system; an electrical supply failure; or failure of the reactor regulating system. Although serious, this class of accident would not normally give rise to a significant release of radioactivity even within the reactor containment system.

Much more serious is the possibility of a "dual mode failure". This could be caused by the failure of any one of the process systems together with the simultaneous and independent failure of one of the safety systems. Of greatest concern are the following:

- loss of primary coolant (e.g. pump failure or pipe rupture) combined with loss of emergency coolant;
- loss of primary coolant plus failure to shut down the reactor.
- loss of regulation (e.g. control of power) combined with failure to shut down the reactor.

At present, although this is subject to review, the AECB requires that, in the event of a major (dual mode failure) accident, no member of the public will be exposed to more than 25 rem whole body radiation (note that 250 rem whole body radiation would give rise, within 30 days, to a fatality rate of 50 per cent in a population).

A word of explanation concerning the role of the emergency core cooling system (ECCS) may be helpful. During normal operation, not only is a great deal of radioactivity created in the reactor core but also a great deal of thermal energy. If the shutdown system fails to operate in response to a fuel temperature rise, caused by a major rupture in the primary coolant circuit, a rapid escalation of heat and temperature would occur. The purpose of the ECCS is to remove the heat from the core as rapidly as possible.

If, however, both primary coolant and emergency coolant fail there would probably be partial or complete melting of the reactor core. An uncontained complete core meltdown would almost certainly give rise to a large release of radioactivity, the consequences of which were discussed previously. This would only occur, however, in the very unlikely event of the containment system — both reactor building and vacuum building — being breached. (Note that, in the case of a dual mode (or triple mode) failure accident, leading to core meltdown, the vacuum building relieves pressure buildup — steam is condensed by water sprays — and also helps to contain the radioactivity.) This could happen, for example, if the melted fuel were to fall to the reactor floor, melt through the floor, escape into the earth and contaminate a large area. But both Ontario Hydro and AECL have stressed that, in their opinion, even in the highly improbable event of a core meltdown, the containment system would hold. The main reason for this high degree of confidence is the fact that the melted fuel would first fall into the large volume of cool heavy water moderator (about 400,000 litres). This would act as a heat sink — approximately four hours would be required to evaporate the water, during which period the decay heat of the fuel would be about 1 per cent of that at full power. Furthermore, the designers contend that the cooling system embedded in the reactor floor combined with an external water source, which could be hooked up manually, would be able to cope with the residual heat.

Assuming absolute independence of the process and safety systems, the probability of a core meltdown per reactor at Pickering is said to be in the order of 1 in 1,000,000 years. At Bruce, because there are two independent shutdown systems (i.e. shutdown rods and "poison" injection), the theoretical probability per reactor might be considerably lower, perhaps in the order of 1 in 1,000,000,000 years.

However, two well-informed nuclear critics who participated in the hearings, Dr. Gordon Edwards and Ralph Torrie, have argued that the probability of a dual failure could be about 100 times higher than the theoretical levels. This estimate is based on failure rates in the high pressure piping of the primary heat transport system being 10 times higher than has been assumed, and also on the fact that the availability of the Pickering ECCS has been demonstrated to be 10 times lower than postulated by the designers. We believe that the Edwards/Torrie estimate is more realistic than the theoretical probability, not least because the Rasmussen Report has concluded that the probability of an uncontained meltdown in a light water (U.S.)

reactor is 1 in 20,000 per reactor per year (it has been suggested, moreover, that this figure could be out by a factor of "5 either way"). Assuming, for the sake of argument, that within the next forty years Canada will have 100 operating reactors, the probability of a core meltdown might be in the order of 1 in 40 years, if the most pessimistic estimate of probability is assumed.[11]

Evidence to support the Edwards/Torrie position, which is available in the Pickering Safety Reports, indicates that there were in fact (if the commissioning period is included) six loss of regulation accidents within four years. This compares very unfavourably with the design target of one in 100 years. However, as a result of a major study, involving Ontario Hydro and AECL, several improvements have been incorporated, and there has not been a loss of regulation accident since April, 1975. We have noted also that the emergency core cooling system has not met the design targets although there is evidence that the reliability of the system is improving.

Of more serious concern is the fact that a leak was discovered in the wall of the Pickering unit 2 reactor building in June, 1974, and may have existed for 1½ years — this leak "would have reduced the ability of the containment system to limit radioactive release after any unit 2 accident since the beginning of 1973". Measures which have been taken subsequently have resulted in design target levels being achieved. But the concern nevertheless persists because, as Ralph Torrie has pointed out, the "Pickering unit 2 containment would have to operate within target levels for 500 years before the average annual availability would be back within the bounds of the annual regulatory limit".[12]

It is particularly important to bear in mind the possibility of simultaneous failure of critical safety components. This is referred to as "common mode failure". The possibility can be minimized by physical separation of components and by a fail-safe logic which takes cross-linked incidents into account.

Although we do not believe that the loss of regulation accidents, the degree of unavailability of emergency core cooling systems, or the loss of containment incident at Pickering have given rise, in the past, to significant risk to the public, such incidents do not increase confidence in the safety of nuclear power. On the other hand, and most importantly, more failures and incidents are to be expected during the early years of a reactor's life. These occurrences usually lead to improved designs which in turn lead to enhanced reliability. A learning process is continually in effect and it is this process, and its implementation, which gives us confidence in the present and future safety of the CANDU reactor.

Of basic importance in the postulation of nuclear reactor accidents are the health implications. The AECB has established limits on allowable radiation doses associated with single and dual mode failure accidents as well as specifying the maximum of 0.5 rem and 25 rem respectively. The maximum allowable frequencies of occurrence of these accidents are once in three years and once in three thousand years respectively. It has been shown that the additional 0.5 rem per person, the dose limit for a single failure on the basis of the linearity hypothesis, would give rise to an additional 50 induced fatal cancers per million people.[13] In the case of the dual mode failure limits, there would be about 2500 additional induced cancers per million people exposed to a dose of 25 rem.

In assessing the legitimacy of the above limits it should be stressed that no study similar to the Rasmussen study has been undertaken in Canada to assess the reliability of the reactor system as a whole and the consequences of major CANDU reactor accidents. It has been argued that, following the Farmer philosophy, the main emphasis, to ensure a high level of safety, should be on improving the reliability of specific components, processes and assemblies. It has further been argued by Ontario Hydro and AECL that, because the Rasmussen study applies in a general way to CANDU, and because an equivalent study, due to ongoing major design changes, would never be sufficiently up-to-date, such a study would not justify its high cost. We concur with this position, not least because we have great difficulty in understanding how the vagaries of human behaviour can be incorporated into such highly sophisticated models.

The Human Factor

> While the nuclear industry can take great pride from its enviable record, the adverse public reaction to radioactive releases that could be caused by operator error makes it essential that the operator-control room interface be optimized. — *(EPRI Report NP-309)*

Most of the serious nuclear accidents (fortunately no "major accident", as defined previously, has ever occurred) which have been reported on a world-wide basis appear to have been caused by human error. Apart from the massive accident which probably occurred in the USSR (details of which remain obscure, although many lives appear to have been lost), there is no evidence of nuclear accidents involving even a few fatalities. Although modern digital computers, especially "back-to-back" computers, and safety technology in general, have demonstrated an incredibly high degree of reliability in the monitoring, control and protection of nuclear reactors, we do not believe that technology, per se, can be endowed with an "ultimate defence" (against accidents) capability — this must rest with the human operators. And even the most highly trained and conditioned operator may be subject to lapses of concentration. Because we felt that our inquiry had not elicited adequate information relating to the key role of the human operator in reactor operations, we commissioned a study by Canada's two leading human factors (i.e. the man/machine interface) specialists. The summary report by J.W. Senders and Dr. P.J. Foley, which we regard as of particular importance, was completed in June, 1978. Since its completion a report commissioned by the Electric Power Research Institute (EPRI) on the same topic has been published: there is marked agreement between the conclusions reached.[14]

While the estimation of the probabilities of failure of pressure tubes, pumps, computers, electric components, relays and switches is comparatively straightforward, even though operating experience may be limited only to a few years, the assessment of human operator performance is much more difficult.

The basic principles of human behaviour, with special reference to nuclear power, have been stated by J.R. Ravetz.[15] He identifies three principles. The first relates to the need for "commitment at the top of any hierarchy of control". One manifestation of this principle is that it is "impossible for a control group to enforce perfect adherence by operatives to any set of formal rules. They must be allowed initiative to accomplish their tasks as they see fit." The second principle, stated by Ravetz, relates to "the need for commitment at the bottom of the hierarchy". He points out that the quality of workmanship, of operational efficiency and indeed of quality control, specified by management, can never be absolutely guaranteed. According to Ravetz "this problem of safety-control in manufacture may be effectively insoluble". The third principle of human behaviour relates to the inevitable "degeneration of routine tasks". Safety engineering must ultimately rely on the performance of a large number of boring, repetitious and non-active tasks. The conclusions of the Senders/Foley study exemplify the three principles noted above. Because of their eminence in the field, we cannot but accept and endorse their findings.

The following points, which relate to the training, evaluation, skill maintenance, the man/machine interface, and the working environments relating to the human operator, emerged from the Senders/Foley study:

- The training and skill-maintenance of the nuclear operators could be improved — in particular, there is no system for the collection of quantitative data on operator performance on the job which could be applied as feedback to modify and improve the training system. Senders and Foley point out, for example, that "no effort appears to have been made . . . to use well established principles of training";
- The evaluation of nuclear operators does not appear to be a "continuous process". Continuity of performance data collection is essential to the evaluation and maintenance of operator skill. For example, there does not appear to be any means of assessing whether the skill of an operator is maintained, enhanced or diminished after several months on the job;
- In some respects the operation of a CANDU reactor, under computer and "safety" control, is almost "too good" — human operator vigilance is

notoriously difficult to maintain at high levels when everything "always runs perfectly". A much more rigorous programme of on-the-job activities including more realistic simulator work, which embodies highly improbable events and which incorporates feedback, appears to be desirable;

- Although human factors engineering principles have been applied in the overall design of nuclear power control centres, there remain some deficiencies in the design of some instruments and instrument panels. In an emergency situation, it is essential that the control and instrument panels must be optimally designed.
- It is not clear how the operator training programme is dealing with the fact that Bruce G.S. is different, from a human factors standpoint, from Pickering G.S. Because of these differences, there are problems when operators transfer from one plant to the other. Simulators should be programmed as a part of every newly developed system. The complaint that this programme would be too costly does not appear reasonable, given the demands made on the human operator for maintenance of operation, and the serious costs associated with interruption of power output. That there may also be safety issues involved in operator training supports this proposal. With increasing numbers of plants and operators, the low probability events which might occur as a result of operator inadequacy become economically important;
- Senders and Foley make a special point of stressing the importance of encouraging engineers, operators and maintenance personnel to criticize the operating procedures at present in force. There is some circumstantial evidence that criticism of this kind is not always welcomed by management personnel.

Nevertheless, in spite of the above apparent training deficiencies and criticisms, we would stress that the operators with whom we have been in contact are obviously intelligent, articulate, conscientious and very aware of their heavy responsibilities.

Occupational Health and Safety

The Nuclear Generation Division of Ontario Hydro was established in 1958. During the past twenty years about forty million man-hours of work have been undertaken with no occupational fatalities. Workers have averaged two lost time accidents per million man-hours worked and none of these have resulted from radiation exposure. However, although these statistics are impressive, and demonstrate the excellent safety record of the utility,[16] they are not too significant with respect to the effects of radiation exposure. Because most cancers have a latency period of fifteen to thirty years, because the number of workers involved is comparatively small, and because there is a "healthy worker" effect, (i.e. people involved in this kind of work are of better than average health) the statistical significance of existing data may be problematical.

The existing average annual dose for the mechanical maintainers — the highest exposure group — is 2 rems. This, of course, is below the 5 rem/year guideline set by the ICRP. (But see Annex D for recent information which suggests that the 5 rem/year limit should be reduced, by a factor of 10, to 0.5 rem/year.) These workers replace pressure tubes, repair pumps, work on feeder pipes and remove valves from radioactive areas. According to the linearity theory their dose rates, if continued over a thirty year occupational exposure, would be expected to induce 6.5 additional cancers per thousand people. This should be compared with the North American lifetime death rate from cancer which is 200 per thousand people.

The most potentially hazardous operation which can be expected during the lifetime of a CANDU reactor is the replacement of all the reactor pressure tubes. Considerable experience was gained at Pickering in connection with the replacement of cracked pressure tubes in units 3 and 4. A complete retubing operation would require a comparatively large number of skilled workers because of the need to conform to the 5 rem/year limit per worker. This could constitute a major bottleneck in the future operation of Ontario's nuclear power stations, especially if more rigorous standards are introduced.

In general we have concluded that, in view of the excellent safety record of the Nuclear Generating Division of Ontario Hydro, given the meticulous precautions which are taken to monitor dose

rates and exposure levels, the long term risk to nuclear workers, even those at maximum exposure levels, is comparable with the risks encountered in other industries. However, this conclusion is based on the 5 rem/year limit; if it is demonstrated that the level should be appreciably reduced, a reassessment of the risks would be essential.

Safety and Economics: The Trade-offs

In concluding this introduction to CANDU reactor safety, we draw attention to the close relationship between safety and economics. This is by no means unique to nuclear power. For example, the safety level of most major engineering works and systems such as bridges, hydroelectric dams, aircraft, automobiles, roads, high-rise apartments, etc. is dependent upon how much is spent to ensure safety. (Absolute safety is unachievable.) Similarly the budgets of police forces and fire departments determine, in no small measure, the degree of legal and fire protection provided to the public.

But a law of diminishing returns may prevail in some processes and systems; indeed, a point might be reached where safety may not be improved by additional expenditures and may even be compromised. In the case of nuclear power stations, however, it is unlikely that such extreme conditions would arise until after massive expenditures on safety had been incurred. Nevertheless, herein lies a dilemma for Ontario Hydro, the AECB and, by no means least, the public of Ontario. It can be stated simply in the form of two questions:

- how much extra reactor safety can be bought for $X million?
- how much extra is the consumer willing to pay for electricity (10 per cent, 20 per cent or ?) to decrease the probability of a serious release of radioactivity from a nuclear power station from 1 in 100,000 to 1 in 1,000,000 per year?

Although an approximate answer to the first question is probably obtainable, the second is more difficult. Value judgements of a particularly significant kind are involved. The Commission is not in a position to pass judgement: only the public can decide. But we emphasize that the economic implications of nuclear safety must be borne in mind even by the AECB. What applies to nuclear power also applies, in principle — albeit with different safety parameters — to coal-fired generating stations, solar energy, biomass energy, and oil and natural gas. The weighing of the risks associated with each technology is a good beginning. A recent report by Dr. H. Inhaber, a member of the staff of the AECB, addresses the problem.[17]

> Although we are not technically competent to assess the levels of risks associated with the operation of CANDU reactors, our dealings with the staff of AECB have convinced us that no nuclear power station in Canada would be permitted to operate if it were regarded as unsafe in any way.

Siting Nuclear Power Facilities

It is not surprising that many people in Ontario (and doubtless elsewhere) appear to be quite prepared to accept nuclear power, as long as the nuclear power stations, or heavy water plants, or ultimate spent fuel disposal sites, etc. are not located close to their own community. Siting of nuclear facilities is a contentious issue for various reasons:

- there is still a widespread belief that nuclear power stations might explode like a nuclear weapon; this belief is fallacious;
- the association between nuclear power and radiation bestows an aura of mystery on all things nuclear;
- large tracts of land of up to 20,000 hectares are removed from any future agricultural or recreational activity;
- the high voltage transmission lines associated with large nuclear power plants traverse good quality agricultural land and cause inconvenience to farmers;
- the thermal discharge along the shoreline into the littoral zone could potentially affect the spawning of fish.

General Siting Principles and Criteria

The key principles which apply in general to all thermal generating stations (coal and nuclear) and heavy water plants, upon which siting decisions should be based, can be summarized as the principles of need, local acceptance, ensuring minimal health and environmental impact, energy and land conservation, and maintenance and even enhancement of the economic and cultural life of the local

communities. Particularly significant are the land use implications which relate to agriculture, regional planning, management and conservation of water as well as basic ecological concerns.

Siting criteria unique to nuclear stations include:

- an exclusion zone of 1 kilometre, a criterion set by the AECB;
- the availability of very large amounts of water for once-through cooling (nuclear plants require nearly twice as much cooling water as other thermal stations).

The siting principles and criteria are predicated on health, safety and environmental factors and the implications of postulated large scale radioactive releases. During the normal operation of a nuclear power station, it is well known that a small amount of radioactive material may be discharged into the cooling water. This is continually monitored to ensure that the "radiation dose" is less than the recommended limits. As we pointed out in Chapter 4, a unique problem associated with CANDU, because it uses heavy water as moderator and primary coolant, is the amount of the radioisotope tritium produced. Indeed, tritium, an isotope of hydrogen with a half-life of 12.5 years, is released from CANDU reactors as a component in both the airborne and liquid effluents. However, this is below the permitted level.[18] It has been suggested, nevertheless, by the Canadian Environmental Advisory Council[19] that Canada has a special responsibility to investigate thoroughly the biological effects of tritium — we are not aware of any major research in this area.

Of all the environmental implications of electric power generation, probably the least quantifiable is the aesthetic component. Even many critics would concede that aesthetically a nuclear power station is to be preferred to a coal-powered station. On the other hand the siting of any thermal generating station must take account of aesthetic and cultural values, and special weight should be given to preserving areas of natural beauty, areas where native cultures have been established for many generations and areas designated as green belt and recreational areas. The aesthetic implications of nuclear power station siting are not less important than the more quantifiable environmental impacts.

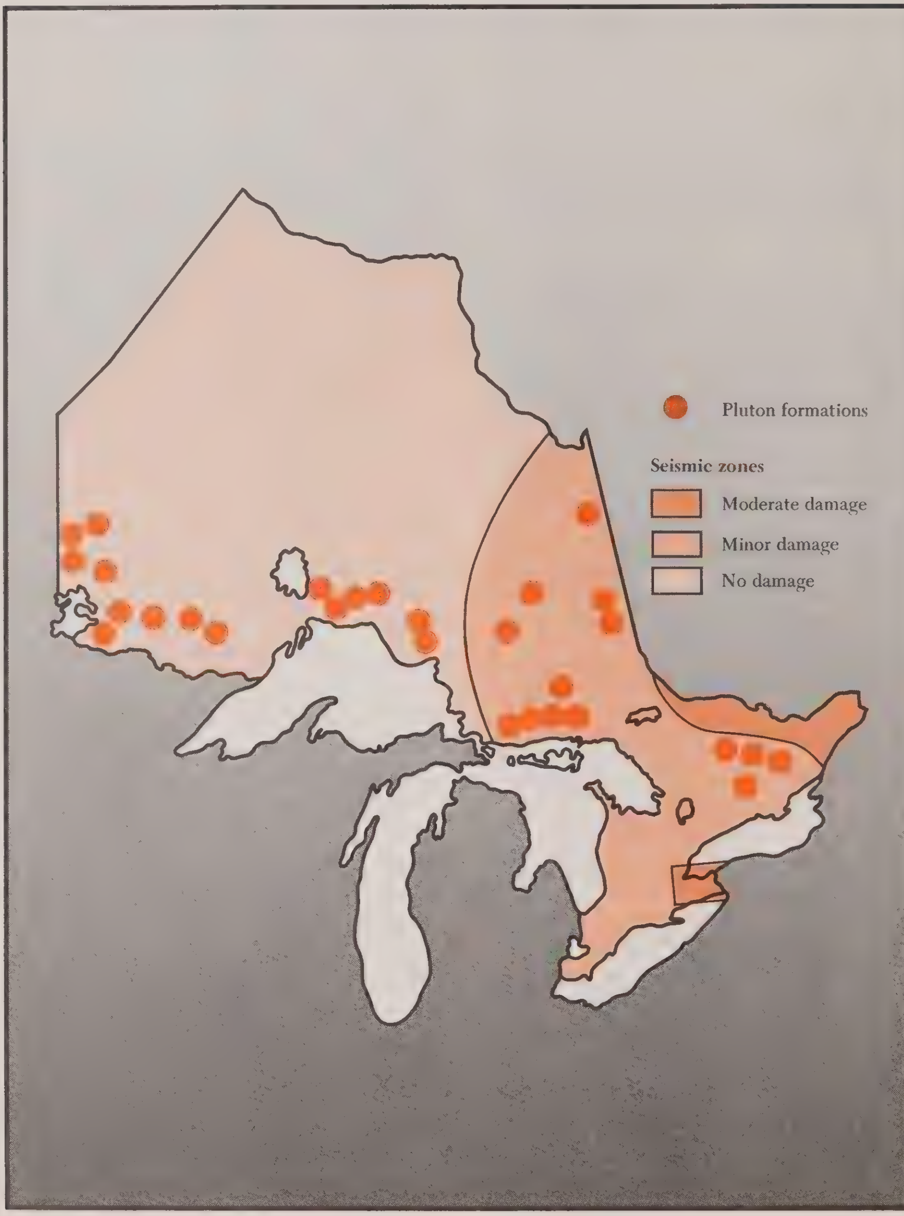
Various siting proposals aimed at minimizing the environmental impact of nuclear power have been studied. The siting of the stations underground is one of the most interesting and practical. Although underground siting would not improve the safety of nuclear stations in an absolute sense, the risk of injury and damage in the event of a major accident would be reduced. From the utilities' point of view underground siting would provide more flexibility in the choice of sites, would probably lead to appreciably reduced transmission line costs and environmental impacts, and would minimize the amount of land required. However, the additional cost of constructing a nuclear power station would be in the order of 20 per cent (and 20 per cent of $3 or 4 billion is not inappreciable). Nevertheless, we believe that serious consideration should be given to the proposal especially in the case of nuclear stations which may go into service twenty-five years hence.

Note on a Nuclear Power Complex

The Bruce nuclear development is the largest projected nuclear power complex in the world. It has also been acclaimed by internationally recognized nuclear scientists and engineers, such as Alvin M. Weinberg, formerly Director of the Oak Ridge National Laboratories, as a model for other countries to emulate. The dedication of a single large area for nuclear power generation, heavy water production, and the disposal of low- and intermediate-level nuclear wastes, as at Bruce, as contrasted with the development of dispersed smaller sites has several major advantages — environmental, as well as economic and social. Insofar as environmental and health factors are concerned, the large nuclear complexes, optimally sited, can minimize the risk to the public in the case of a major nuclear accident for two reasons: first, because they usually have a larger exclusion zone, and secondly, because they are usually located in areas of low population density. Furthermore, for normal operation, the routine radioactive emissions, albeit very small, have less environmental impact than those of a smaller station because of the large radius of the exclusion zone.

The concept of the nuclear complex, isolated environmentally and to some extent socially, has

Figure 6.4 Seismic Zones and Location of Plutons in Ontario



SOURCE Energy, Mines, and Resources, Atomic Energy of Canada Limited and Ontario Hydro

much to commend it: to the average member of the public it signifies that nuclear power has been "contained".

Seismic and Meteorological Considerations

Nuclear power facilities, especially power stations, radioactive waste disposal sites, etc. should obviously not be located in earthquake prone regions. Fortunately, most of Ontario is characterized as seismic Zone 0 and Zone 1, although the Ottawa Valley, the St. Lawrence Valley and the Niagara Peninsula are categorized as Zone 2 (see Figure 6-4).

Before a nuclear power site can be licensed, a detailed study of the seismic characteristics of the area is undertaken to estimate the frequency of occurrence of earthquakes with varying degrees of severity. This investigation determines the suitability of the site from a seismic standpoint and, if suitable (suitability is largely based on the past earthquake history of the region), design criteria for the major reactor systems are developed. For example, the primary cooling system and the fuelling machines are designed to withstand more severe earthquake conditions than the emergency core coolant injection system. We believe that potential earthquakes, of appropriate severity, have been taken into account in the siting and basic design of CANDU reactors, and that the probability of an earthquake condition causing a dual mode failure is very small.

Because of routine releases of radioactive gases, even though at very low concentrations, and because, more importantly, of the possibility of a major nuclear accident with consequent breach of containment, nuclear power stations should be located down wind from large concentrations of population. The same applies to heavy water plants, although, unlike Pickering, Bruce is located sufficiently far from densely populated areas that the requirement is not quite so important. Of course, all nuclear facilities must be designed to withstand hurricane conditions with wind velocities in the order of 200 km/hour. We have no misgivings about the siting of Ontario's nuclear facilities on meteorological grounds.

Contingency Plans

If a serious accident should occur at a nuclear power station, common sense dictates that well developed and rehearsed plans must be in place. In siting power stations and in the future planning of the area reasonably adjacent to the station, contingency plans must be part of the overall planning process. Although Ontario Hydro is responsible for on-site action in the event of an emergency (this plan is in place and is rehearsed annually), the principal responsibility for co-ordinating off-site action is vested in the Ontario Ministry of Labour. A Contingency Control Group with representatives from the Ministries of Agriculture and Food, the Solicitor General, the Environment, Health, and Labour and from Ontario Hydro is charged with putting the contingency plans into effect.

Two full scale rehearsals of the contingency plan have been staged since 1973. However, we have the impression that because the likelihood of a major nuclear accident is very small, contingency plans are not regarded as an essential component of nuclear safety. For example, we believe that it would be appropriate for full scale rehearsals to be held at least annually and that these should be carefully reviewed and evaluated by independent observers.[20] Furthermore, the reports on the rehearsals should be made readily accessible to the general public and education of those living in the immediate vicinity of a nuclear power station should be encouraged. It would also be appropriate, we believe, for local ratepayers' associations, and perhaps other public interest groups, to be informed of and to participate in rehearsals of the contingency plans.

Management of Thermal Wastes

All large scale thermal generating stations in Ontario discharge heated water from their condensers into lakes or rivers. This has been referred to as "thermal pollution". However, there are circumstances where these discharges can be beneficial to the ecology during, for example, cold weather when a warm dynamic thermal plume may be beneficial to some marine life. Nevertheless, during warm periods, the thermal plume may have a detrimental effect on, for example, fish-spawning areas.

The general public does not fully appreciate that the amount of energy discharged into the Great Lakes in the form of low quality thermal energy is over twice as great as that generated in the form of electricity. A major distinction between nuclear and fossil-fired stations is that the former, on average, discharge about 50 per cent more thermal energy into the lake than do, for example, coal-fuelled stations. The reasons are first, that fossil-fuelled stations discharge some thermal energy through the smoke stacks and secondly, that coal-fuelled stations can operate at higher temperatures and hence are more efficient, wasting less thermal energy.

The environmental implications of the thermal discharges are by no means understood, because of the highly complex nature of the aquatic environment. A National Research Council Committee on Environmental Quality, for example, has concluded that:

> The effects of thermal discharges are found to be specific to the site of the discharge depending on the organisms living in the area and on the nature of the area. Consequently, a limit on waste heat which might serve to protect one locality might do considerable harm in another. . . . Organisms which thrive in cold water will decrease and the ones which tolerate heat better will increase.

Most biologists agree, however, that if the number of major thermal generating stations on their shores escalates, the potential threats to the littoral zones of the Great Lakes will also escalate. Indeed, both Fisheries and Environment Canada and the Ontario Ministry of Natural Resources have expressed serious concern about the environmental impacts of the thermal discharges from an increasing number of nuclear power stations. In particular, the Ministry of Natural Resources has advocated extending the condenser water discharge pipes well beyond the littoral zone of the lakes. Ontario Hydro estimates the cost to be between $50 million and $100 million per thermal generating station.

Undoubtedly the most desirable and efficient method of dealing with thermal discharges, at least in part, is to utilize as much of the waste thermal energy as possible for district heating purposes and for heating greenhouses. Because the temperature of this discharged energy is only about 11°C above that of the lake water, the bulk of it is virtually unusable. However, plans are already in hand to utilize the moderator coolant of Bruce B Generating Station to heat about 50 hectares of greenhouses in the vicinity of the generating station. This scheme would utilize about 2 per cent of the thermal energy normally discharged into the lake.[21] If waste heat from generating stations can be converted into useful heat, the environment will gain and so will the people of the province.

Although we do not believe that thermal discharges from existing nuclear power stations pose a major environmental threat at present, we strongly endorse the concept of utilizing these discharges. We note also that a major expansion in the number of thermal generating stations on the shores of the Great Lakes could have an irreversible and probably undesirable influence on the ecology of the Great Lakes.

Siting of Heavy Water Plants

The heavy water facilities serving Ontario Hydro's nuclear power programme are located on the site of the Bruce Generating Station. The technical details and the economics of heavy water production are considered in Chapters 4 and 7. The co-location of nuclear power generation and heavy water production has several advantages — e.g. large amounts of electric power, steam, and water are readily available; security measures are in place.

In addition to the usual environmental problems associated with large industrial chemical plants — chemical and thermal pollution, oil spills and leakages, and sanitary wastes — heavy water plants routinely discharge small quantities of hydrogen sulphide (H_2S). This toxic gas is contained in the process water effluent, and in the gas phase of the process via a "flare stack" (when H_2S is burned in sufficient quantity, sulphur dioxide, SO_2, is created). The major health and environmental threats of heavy water plants arise if large emissions of H_2S and/or SO_2 occur — these might arise for three reasons: failure of the pressure envelope; chemical imbalance in the process; during start-up.

The health and environmental impact of SO_2 is

reasonably well understood because this toxic gas is widely used in industry. Under normal operating conditions, the Bruce heavy water plants are meeting the environmental standards set for SO_2 levels. But the discharge of H_2S constitutes a potentially more serious problem. In a statement prepared for the Canadian Environmental Advisory Council, which referred to effects on humans, the AECB stated:[22]

> Most information is based on post-accident investigations and industrial experience, and so highly injurious or lethal concentrations in air are not accurately known. It has also been suggested that long-term exposure to acceptably low concentrations of H_2S can cause chronic systemic poisoning and sensitivity to H_2S on future short-term exposure to high concentrations.

The AECB has established standards for permissible levels of H_2S contamination of the atmosphere and for monitoring these levels. As is the case at nuclear power stations, AECB inspectors are responsible for on-site inspections of heavy water plants. Quarterly reports, safety reports and special incident reports, relating to the heavy water plant operations, must be submitted by Ontario Hydro.

Another environmental concern, which arises also in thermal power generation, relates to the impact on the micro-organisms contained in the condenser coolant stream. The process is referred to as "entrainment". Minute life forms are killed by a combination of water processing for deuterium extraction, heat and turbulence in passing through the plant. Probably the effect of the water processing is the most lethal. The extent to which the populations recover through rapid reproduction in areas remote from the plant is unknown. Compared with the lake water volume, the quantity of water involved in cooling is negligible, but there is no doubt that losses of small fish and higher forms of organisms are probably irreversible. Because information relating to these phenomena is inadequate, there should be increased research efforts. Protection of the ecology of the Great Lakes, as mentioned earlier, is essential.

We do not have the technical competence to judge the levels of risk associated with heavy water production, but our layman's judgement suggests that the plants do not constitute a hazard to the environment and that all steps are presently being taken to ensure their safe operation.

Public Involvement

During the past few years Ontario Hydro has been increasing its efforts to involve the general public in discussions relating to the siting of thermal generating stations and the routing of bulk transmission lines. Furthermore, the Ontario Ministry of the Environment, and especially the EAB, has not only identified key environmental problems, such as the Elliot Lake uranium mine and mill tailings, but has stimulated major environmental studies, the conclusions of which have been, and continue to be, debated in public. This Commission also has done all in its power to encourage public participation.

We have concluded that public participation, especially in the discussion of such sensitive subjects as the siting of thermal generating stations, radioactive waste disposal facilities, etc. is essential. How it can be most effectively integrated into the decision-making framework will be discussed and debated during our public workshops, seminars and hearings scheduled for January, 1979.

Interim Storage of Spent Fuel

We turn now to the "back-end" of the fuel cycle and, in particular, the management of spent fuel.[23] It is a complex problem from all standpoints and a highly contentious issue. In this section we consider the interim storage (i.e. up to forty years) and transportation of spent fuel, and in the next section its ultimate disposal.

The extreme lethality of a freshly removed spent fuel bundle is such that a person standing within a metre of it would die within an hour. During the next forty years (and probably for thousands of years), the management of hundreds of thousands of such bundles (in Ontario alone), which at all times must be isolated from the earth's ecosystem, will clearly present a problem of massive proportions. The major radioactive constituents of CANDU spent fuel on removal from the reactor are given in Table 6-4. The radioactivity at this stage — and indeed for about 500 years thereafter —

Table 6.4 Nature of Spent Fuel

Constituents of 1 kg.	Spent fuel	Fresh fuel
U-238	984 grams	993 grams
U-235	2 grams	7 grams
Actinides	5 grams	
Fission Products	9 grams	
	1000 grams	1000 grams

is due to the fission products. Of key economic significance is the potential energy, in the form of plutonium, contained in the spent fuel. We discussed "reprocessing" and advanced fuel cycles in Chapter 4. See also Annex F.

On removal from a reactor a spent fuel bundle is transferred by remote control from the fuelling machine to a storage bay filled with circulating water within the station in which the water level is at least three metres above the stacked bundles. These bays have limited storage capacity. At Pickering A, the original spent fuel bay is now full and an auxiliary fuel bay has been operational since the spring of 1978. Pickering has space for 80,000 bundles in the main bay and 190,000 bundles in the auxiliary bay, while at Bruce the corresponding capacities are 27,000 and 262,000 bundles respectively. The interim storage of the thirty year lifetime spent fuel output of Pickering A operating at 80 per cent capacity would require a 2,000 m^3 storage bay. Alternatively, if dry storage in as yet experimental steel and concrete canisters were to be used (each canister containing 216 bundles), a total of 1500 canisters would be required and these would occupy an 8 hectare site.[24] The aggregated spent fuel generated in Ontario to the year 2000 for various nuclear power programme scenarios is shown in Table 6-5.

Assuming a nuclear power programme based exclusively on the existing once-through CANDU fuel cycle, the two spent fuel interim storage options are:

- to design and construct on-site storage bays (i.e. circulating water) capable of handling all the spent fuel generated by the station during its lifetime, and subsequently transfer the spent fuel to an ultimate disposal facility — when it is available. Note that the design and construction of the disposal facility would include an on-site spent fuel immobilization plant[25] which would prepare spent fuel for placement in the ultimate disposal facility;
- as above but, under strict safeguards, to export spent fuel to a foreign country or countries. This option would not preclude the necessity of proceeding with the development of the ultimate disposal facility since Ontario or Canada would likely be expected to assume responsibility for the remaining high level liquid wastes once the useful plutonium had been extracted.

The type ("wet" or "dry") of interim — up to forty years — storage of spent fuel in on-site bays will of course depend on the degree of deterioration of the spent fuel bundles in circulating water. We understand that chemical treatment of the water to optimize the integrity of the fuel bundles is already being done. If wet storage proves to be impractical over long periods, the alternative would be to utilize dry storage, as mentioned previously.

On the other hand, if it is decided to reprocess the spent fuel commercially (in Ontario), the two interim storage options would be:

- Short term storage of spent fuel in on-site storage bays (say for a minimum of five years); followed by transport of spent fuel to a central interim storage facility, probably serving all the nuclear generating stations in the province and perhaps in Canada; followed by reprocessing of spent fuel and fabrication of mixed oxide fuels; followed by vitrification of high-level liquid wastes from the reprocessing plant; followed by transport of solid high level wastes to the ultimate disposal facility;
- On-site storage of all spent fuel for the lifetime of the reactor; followed by transport of spent fuel to a reprocessing plant; followed by the steps outlined above.

The difference between the above options is that the first involves a central interim storage facility while the second does not. The latter option is unlikely because, in an expanding nuclear programme which included reprocessing, the large amounts of spent fuel would more sensibly be stored on the same site where it would subsequently be reprocessed.

Clearly the case for a central interim storage facility is fundamentally predicated on whether or not it is decided to reprocess CANDU spent fuel and to recycle the plutonium. If, for example, no reprocessing is contemplated until some time after the turn of the century — a position which we endorse — then there is no compelling need for a central interim storage facility.[26] From health, environmental and safety points of view, we believe

Table 6.5 Spent Fuel Generated by the Ontario Nuclear Programme, Various Scenarios, 1980-2000

	Darlington		Darlington plus 6000 MW		Darlington plus 16000 MW		Darlington plus 26000 MW	
	(Tonnes)	(Cubic metres)	(Tonnes)	(Cubic metres)	(Tonnes)	(Cubic metres)	(Tonnes)	(Cubic metres)
1980	3,500	7,000	3,500	7,000	3,500	7,000	3,500	7,000
1985	8,500	17,000	8,500	17,000	8,500	17,000	8,500	17,000
1990	17,000	35,000	18,000	36,000	19,000	38,000	20,000	40,000
1995	26,000	50,000	30,000	60,000	34,000	68,000	36,000	72,000
2000	35,000	70,000	40,000	80,000	46,000	92,000	60,000	120,000

SOURCE Based on data from Ontario Hydro and estimates by RCEPP.

that the existing CANDU fuel cycle is much preferable to an advanced fuel cycle which would necessitate reprocessing and the management of high-level liquid wastes.

Transportation of Spent Fuel

The transportation of spent fuel is permitted after a five year cooling period in on-site storage bays and will be an important component of the nuclear fuel cycle in the future. The hazards associated with transportation, in particular the possibility of accidents and the threat of hijacking, are real possibilities. Hence, the minimization of handling and transporting spent fuel is a desirable objective.

CANDU spent fuel is transported in flasks 3 metres long and 2 metres in diameter; several of these are undergoing extensive testing at the AECL Whiteshell Laboratories. The flasks weigh 50 tonnes and contain 3.5 tonnes of spent fuel when fully loaded. The walls are of 9 cm steel and 16.5 cm lead shielding. The integrity of the flasks has been tested under extreme conditions, such as 50 km/hour impacts, gravity drops of 1.3 m on to a hardened steel pin, and immersion in an 800°C temperature environment for 30 minutes. According to AECL the release of radioactivity from the flask would probably occur only after a collision at speeds of 120 km/hour and a subsequent severe propane fire. The probability of such an accident is said to be in the order of 1 in 70 million shipments. In the more than 500 shipments which have been made in Canada to date no accidents have occurred.

Ultimate Disposal of Spent Fuel

There already exists, in the world, probably tens of thousands of tonnes of high-level radioactive wastes which have been produced by nuclear weapons and by nuclear power programmes respectively, in about equal amounts. Accordingly, the question facing society is not whether we can adequately isolate these wastes from the biosphere for thousands of years, but rather how quickly it can be done.

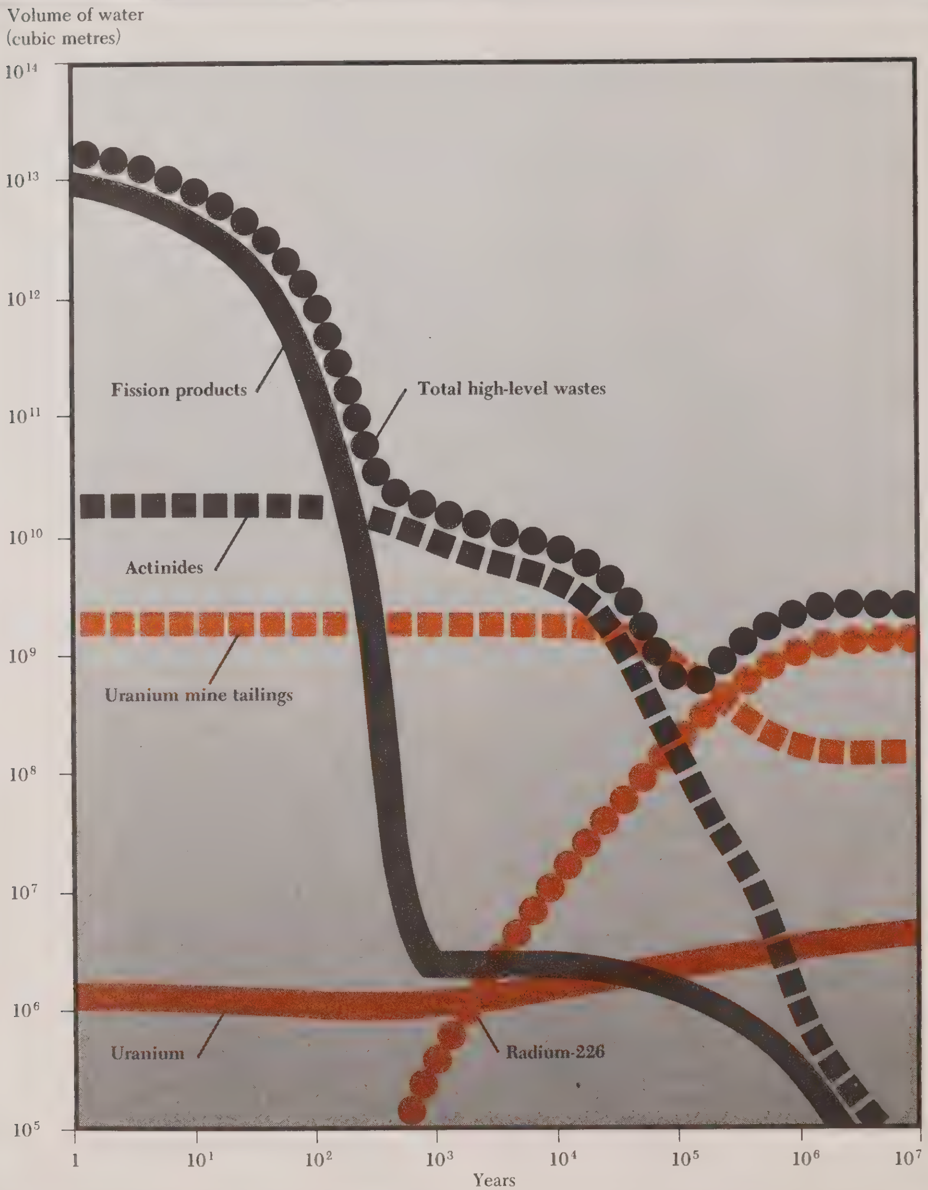
We assume, at present and in the foreseeable future, that Ontario will not pursue a "spent fuel reprocessing path", as discussed earlier, and that the disposal problem relates to the ultimate disposal of spent fuel. On the other hand, on-site wet spent fuel storage (or, if impracticable, an interim on-site dry storage facility), is clearly retrievable storage, and a decision to reprocess or not to reprocess spent fuel can be delayed for at least twenty years. The reprocessing option will remain open until the year 2000. Meanwhile the research, development, and demonstration programmes relating to the ultimate disposal of spent fuel and other high-level radioactive wastes should, we believe, proceed on a high priority basis. This conclusion, as will be shown later, is common to all the major spent fuel management studies which have been undertaken in recent years.

Decay Characteristics of Spent Fuel

As we have stressed previously, spent nuclear fuel remains extremely radioactive and toxic for hundreds of years, very radioactive and toxic for thousands of years, and moderately radioactive and toxic for tens of thousands of years. The decay curves shown in Figure 6-5 illustrate this very dramatically.

A word of explanation concerning the graphs will be helpful. Both vertical and horizontal scales are logarithmic — it is quite impossible, because of the magnitudes and time periods involved, to use linear scales. The vertical scale shows the "ingestion hazard index", which corresponds to the number of cubic metres of water which would be required to dilute the radioactivity from the high-level wastes produced by a 1000 MW CANDU reactor per year, to standards acceptable for drinking water. Although this hazard index is only a crude measure of the potential danger of the radioactivity, because many environmental factors are involved, it nevertheless gives an idea of the serious nature of the problem. The horizontal scale indicates the storage time in years. For the first 600 years the radioactivity is due, almost exclusively, to the fission products, and for the following 100,000 years the main radioactive isotopes are plutonium and americium. For comparison purposes, the relative ingestion hazards of uranium ore and uranium mill tailings, as well as the high-level wastes, are also shown.

Figure 6.5 Ingestion Toxicity[1] of Spent CANDU Reactor Fuel, Once Through Natural Uranium Cycle



1 Ingestion toxicity is the volume of water required to dilute the wastes to public drinking water standards.

SOURCE Based on data from *Reviews of Modern Physics*, Vol. 50, No. 1, January 1978, and from S. Banarjie, McMaster University.

Major Studies: Some General Conclusions

During the past eighteen months several major studies, devoted wholely or in part to radioactive waste management and spent fuel disposal, have been published. Notable are the Flowers Report;[27] the Ford-MITRE Study;[28] the American Physical Society Working Group Study;[29] the Kärn-Bränsle-Säkerhet Study in Sweden;[30] and two Canadian studies — the first was sponsored by Energy, Mines and Resources Canada and was headed by Dr. F.K. Hare, Director of the Institute for Environmental Studies at the University of Toronto,[31] and the second was a study undertaken by Dr. R.J. Uffen,[32] Dean of Applied Science at Queen's University. Some of the major conclusions of these studies, in very condensed form, are given below:

> these wastes already exist in substantial quantity and a safe method for their long-term disposal is in any case required whatever is decided about nuclear development in the future. We are clear that such a demonstration will require a substantial programme of research. — *(Flowers Report, Paragraph 338)*

> We believe that nuclear wastes can be disposed of permanently in geological formations in such a way that there is very little prospect of material escaping into the environment. Moreover, even unlikely failures of repositories in the distant future would not have large consequences to human populations. This is true independent of whether the wastes disposed of are spent fuel or the re-solidified and trans-uranic wastes left after reprocessing and recycle. — *(Ford-MITRE Report, page 245)*

> Effective long-term isolation for spent fuel, high-level or trans-uranic waste can be achieved by geologic emplacement. A waste repository can be developed in accord with appropriate site selection criteria that would ensure with low probability that erosion, volcanism, meteorite impact and other natural events could breach the repository. The possibility of inadvertent human intrusion also can be made remote and limited in consequences. — *(Report to the American Physical Society by the Study Group on Nuclear Fuel Cycles and Waste Management, page S6)*

> Radioactive substances from a final storage can only be released by the ground water. The final storage must be arranged in such a way that such a release cannot damage the ecological system. It is then important to remember that the activity of the radioactive substances in the waste diminishes very slowly. The final storage is therefore arranged so that the migration of these substances is either prevented or delayed for a long time, thus insuring that the concentration of radioactive substances which may reach the biosphere will be harmless. For this reason, the design of the final storage provides for a number of successive barriers. — *(Kärn-Bränsle-Säkerhet Report* Handling of Spent Nuclear Fuel and Final Storage of Vitrified High-Level Reprocessing Waste, *page v)*

The Hare report and Dr. Uffen's study are of special interest to Ontario, not least because this province possesses more than 95 per cent of the spent fuel in Canada, and the percentage is increasing. (A Standing Committee of the House of Commons is at present studying the findings of the Hare Report.)

Both Dr. Hare and his colleagues as well as Dr. Uffen appeared before us, on separate occasions, to present their respective reports and to be cross-examined.[33] We have attempted in Table 6-6 to summarize their major conclusions, in a comparative form, and to add our own comments and conclusions.

In the technical sections which follow we have quoted extensively from the Uffen Report, especially in connection with siting criteria.

Technical Criteria

The alternative methods of ultimate disposal of high-level radioactive wastes being given serious consideration, globally, include burial in stable geological formations such as salt or hard rock, and burial beneath the deep ocean floor. Research efforts in Canada are concentrating on disposal in hard rock formations such as granite.

Safe geological disposal depends to a large extent on the characteristics of the particular disposal site. It depends, in particular, on the number and individual integrity of the barriers which contain the spent fuel and isolate it from the earth's ecosystem. The first barrier would probably be based on vitrification — the crushed spent fuel, together with glass-making materials (silica, etc.), would be heated in a stainless steel crucible until glass is formed. Subsequently, the crucible would be

Table 6-6 Comparative conclusions on the management of nuclear wastes: the Hare Report, the Uffen Report, and the Commission's conclusions

	The Hare Task Report
Is a national plan needed for the management and disposal of radioactive wastes?	Such a plan is urgently needed. It should cover all aspects of the nuclear fuel cycle (from mining and milling to ultimate disposal); it should also cover radioactive wastes from other sources (industry, hospitals, universities, etc.)
Should demonstration, beyond reasonable doubt, that a method exists to ensure the ultimate safe containment of spent fuel be required before there is a major commitment (in Ontario) to nuclear power?	Because there are "good prospects for the safe, permanent disposal of reactor wastes and irradiated fuel", the Hare position is that "we see no reason why the disposal problem need delay the country's nuclear power program, provided that the government proceeds immediately to the program of research and development in the following recommendations." Time limit on the scale of the nuclear programme is mentioned based on progress in the development of disposal technologies.
Do present accumulations of stored spent nuclear fuel constitute a health hazard?	"The mass and volume of these materials are not large and they present no immediate hazard." On-site water-filled "bay" storage is used universally and a considerable amount of experience has been gained; thus, little hazard is associated with this method.
What are the major environmental concerns? Are the wastes containable?	". . . the radiological impacts on natural ecosystems must be considered in addition to the impacts on human health and safety." The possible escape of radioactive material will depend on the movement and quantity of ground water and the extent to which leaching of the immobilized wastes occur. This is the major environmental concern although the potential effects of earthquakes and glaciation should also be borne in mind. "After examination of the techniques involved we believe that the routine operations needed to prepare . . . the wastes . . . in disposal sites should create no significant environmental hazard.
Is a central interim storage facility necessary?	"Utilities should plan on storing irradiated fuel at the nuclear power plants when it is produced at least until 1990, if not longer, to avoid shipping it more than once." It is recognized that "additional interim fuel storage capacity will clearly be needed." The concept of water-filled pools for interim storage with concrete canisters as a possible alternative method of storage is endorsed.
What type of ultimate disposal facility is required?	"Of the various options . . . we consider underground disposal in geological formations to be the most promising in Canada."

The Uffen Report	The Commission's Conclusions
"The proposed Nuclear Control Board of Canada should proceed as fast as possible to develop 'guidelines for permanent disposal of High Level Wastes' analogous to the existing guidelines for low level wastes."	We endorse the Hare and Uffen conclusions. We stress the urgency of the need for concentrated research and development programmes.
Uffen is unequivocal in recommending that no nuclear programme be committed in Ontario, of "capacity greater than 20,000 MW", until "it has been demonstrated beyond reasonable doubt that a method exists to ensure the safe containment of the long-lived, highly radioactive waste for the indefinite future."	We endorse the Uffen conclusion. However, we go further and conclude that continuous monitoring of waste disposal research should be undertaken by an independent panel of experts, reporting to the AECB. This corresponds to the Uffen proposal for a "Canadian Nuclear Waste Management Advisory Council." If adequate progress is not being made, say, by 1985, the nuclear power programme should be reassessed and a moratorium on additional nuclear stations should be considered.
Professor Uffen does not speculate on the safety of the existing spent fuel bays. However, he implies that it would be desirable to minimize the time the spent fuel remains in on-site storage, by providing an interim spent fuel storage facility as quickly as possible.	The existing spent fuel bays do not give us cause for concern, except insofar as the possibility of sabotage or terrorist infiltration of a nuclear generating station is concerned. Experience on a global basis, with the storage bays appears to have been consistently good.
Ground-water leaching and seepage over extremely long periods are considered to be the major environmental threat. The extent of these physical phenomena will depend on the integrity of the rock (e.g. the absence of joints, fractures, fissures, and faults), which may, for example, be impaired by drilling and blasting operations required in constructing the facility. Uffen believes that the degree of containment cannot be determined until after comprehensive research has been undertaken.	We support, in full, the Uffen conclusions and the Hare conclusions in part. There is some evidence, admittedly based on some United States work, that the waste-disposal problem may prove appreciably less tractable than was originally believed.
Such a facility is endorsed, with the proviso that Ontario Hydro "should not, at the present time, enter into any formal agreements concerning radioactive waste management, which involve or presuppose a commitment to reprocessing used fuel."	We prefer on-site (i.e. generating station site) spent fuel storage to a centralized facility. We believe that a central facility would presuppose the reprocessing of spent fuel; it would also involve more transportation and social and environmental problems. However, on-site water storage for periods of from thirty to thirty-five years would depend on measures being developed to ensure no fuel bundle failures due to corrosion over this period.
The preferred possibility is disposal "in deep underground cavities (about 1 km deep) excavated in plutonic rocks (like granite) in stable geologic areas such as the Canadian Shield where seismic and tectonic activity are very low".	We concur with the Hare and Uffen conclusions. Earlier in this chapter we have presented the geological site criteria recommended by the Institute of Geological Sciences and endorsed by Professor Uffen.

Table 6-6 (continued)

	The Hare Task Report
Where should the ultimate depository be located?	Plutons in the Canadian Shield in Ontario are the preferred location, and "perhaps as many as 40 or 50 of these plutons may merit such detailed investigation." The depository must be located in a "reserve area" much greater than that of the facility itself.
How adequate is the Canadian research and development effort relating to the ultimate disposal of high level radioactive wastes?	"The overall Canadian program of research and development is well conceived, but has received much too little financial support and priority. A large increase will be needed in the scale of geological, geophysical, geochemical and engineering research directed towards the investigation of disposal sites and the task of rendering them operational as repositories." "More research and development is needed into immobilization technology, especially as regards the disposal of irradiated fuel."
What regulatory body, or bodies, should be responsible for establishing criteria relating to the siting of ultimate spent-fuel repositories and for monitoring and inspecting their operation?	"AECB is the appropriate body to establish the criteria for siting and operating all waste management facilities and should publish the criteria at an early date." "AECB is also the logical body to determine the long-term monitoring that will be required at the repositories."
How should the ultimate waste repository be financed?	"The Government of Canada should finance all the cost of developing the technology for safe storage and disposal of radioactive wastes." "The cost of building and operating central storage and disposal facilities should be recovered through charges against the organizations producing and supplying the radioactive waste."
Should Ontario sell its stocks of spent fuel to selected foreign nations?	There is no reference to this question in the Hare Report.
How should the public be involved in decision-making in connection with radioactive waste disposal and related matters?	"AECL should actively seek more comment and discussion of their programs than they have in recent years. Their program documents and progress reports on waste management should not only be public documents but they should be sent to interested groups and individuals in an active search for comments." Public symposia on waste management should be held at least once each year, and wide public consultation is strongly recommended.

The Uffen Report	The Commission's Conclusions
The location of the ultimate disposal facility should be based on extensive testing of suitable sites in Ontario. A demonstration site "would be established only after a battery of geologic, seismologic and engineering tests of the rock formations in the laboratory and the field."	We endorse completely the Hare and Uffen conclusions.
Professor Uffen supports the Hare conclusions relating to "disposal site" research and development. Regarding the immobilization of spent fuel he concludes: "Research and development into suitable methods of encapsulating or "fixing" the unreprocessed used fuel bundles should be undertaken as soon as possible on an urgent basis."	We endorse both the Hare and the Uffen conclusions. During the cross-examination of the AECL panel on this topic, we were assured that the research and development programmes on spent-fuel management and disposal are of top priority. In particular, we conclude that these programmes should be given far higher priority than the research relating to fuel reprocessing and advanced (e.g. thorium) fuel cycles.
Professor Uffen supports the provisions of Bill C-14, especially where they relate to nuclear waste management and the associated mandatory public hearings. He emphasizes the importance of establishing a Waste Management Advisory Council which would report to the Minister responsible for the proposed NCB. (The NCB would supersede the AECB under Bill C-14.)	While endorsing fully the conclusions of Hare and Uffen, we have concerns relating to the respective roles of the AECB and the EAB which have not been adequately defined, in connection with the ultimate disposal of spent fuel. We endorse the concept of the Advisory Council.
"The permanent disposal site should be owned by the Canadian Government, but operated jointly by agencies of the federal and provincial governments."	We concur with the Hare and Uffen positions. However, we have concluded that the total costs of spent-fuel management — as well as radioactive waste management, in general, including projected decommissioning costs — should be reflected in electric power and energy rates.
"Canada should also explore the possibility of selling its used fuel bundles to nations which are willing to accept international regulations. . . ."	We endorse the Uffen conclusion and believe that a major effort should be directed into this possibility.
"The fiascos which have developed in Canada (Madoc, Ontario) . . . might have been avoided if clear statements of the government's policies had been made public and if deliberate, open, public information programs had been launched prior to initiating site evaluations."	We strongly endorse the Hare and Uffen conclusions. Our Debate Stage Hearings on "Decision-Making and Public Participation" will be held in January 1979.

sealed and would constitute a permanent container. The remaining containment barriers would be essentially geologic. The problems of site selection and rock properties are very complex, as illustrated by the following list of technical criteria identified in the Uffen Report:[34]

- the rock type should be homogeneous and massive;
- the rock formation should be thick enough to ensure isolation (i.e. in the order of 100 metres);
- the repository should be deep enough to withstand externally imposed changes (i.e. greater than 300 metres deep);
- the rock should be free of joints, fissures and faults;
- the thermal diffusivity of the rock should be great enough to dissipate the heat readily;
- the thermal expansion of the rock should be uniform and free of incipient weakness due to overheating;
- the rock should not be susceptible to radiation induced, structural weakness;
- the chemical characteristics of the rock should not be conducive to corrosion of the used fuel containers;
- the chemical characteristics should favour chemical containment (i.e. good ion exchange properties);
- the permeability of the rock to ground water flow should be minimal;
- the site should be remote from geological structures known to have been active through recent geologic time;
- the site should be in a region of low seismicity;
- the site should be free of abnormal in situ stresses as evidenced by rock bursts;
- the site should be devoid of surface waters and remote from drainage systems leading to populated areas;
- the site should be unlikely to be of potential value for future mining;
- the site should be remote from human activity such as mines, boreholes, major excavation, tunnels or dams (at least 15 km, has been suggested);
- the site should be suitable for hydro-geological monitoring over long periods of time (at least 1000 years);
- the underground repository should be designed to withstand ground accelerations due to regional seismic activity, and isostatic adjustment;
- the repository should be designed to withstand flooding, sea-level changes, permafrost and erosion accompanying climatic changes;
- the repository should be capable of being backfilled and sealed off permanently.

Canada's Geologic Research Programme

AECL's high-level radioactive waste disposal research is being undertaken in co-operation with the Geological Survey of Canada. The basic guidelines are:

- the rock should have low economic value and not be close to other formations with actual or potential economic value;
- the formation should be large enough to accommodate a buffer zone of significant size;
- the formation should have high integrity with a minimum of cracks, faults and joints;
- the formation should be in a zone of low seismic activity;
- the formation should be such that the wastes will be isolated from moving ground water.

The major technical questions facing Canada and other countries include determination of the best type of rock, packing, and container, as well as the optimum depth for the waste emplacement. Fortunately, major research programmes aimed at these problems have been initiated by several countries. In Canada, and especially Ontario, there has recently been a formal commitment, on the part of governments and the nuclear industry, to deal with waste management and ultimate disposal.[35]

Rock types currently under consideration for use as a waste depository are rock salt, hard rocks such as granite, and tufaceous rocks such as basalt, peridotite and limestone. Rock salt appears to be the preferred medium in the United States and West Germany. Salt is a good conductor of heat, and its plastic characteristics enable it to flow and seal any cracks or man-made penetrations which may take place in the depository. The very existence of rock salt implies that it has remained inaccessible to water for millions of years. However, salt has a low sorption capacity, and would dissolve

easily if water somehow entered the repository. The theory has also been put forward that the heat generated by the radioactive wastes might cause the material to sink downward through the salt, possibly entering the water flow which surrounds all salt domes. In addition, salt is often an indicator of the presence of other useful minerals, which might become valuable in the future, and therefore might result in mining activity which could disturb or penetrate the depository at some future time.

Granite plutons are currently the favoured disposal medium in Canada. A pluton is a small, igneous, usually homogeneous geological protrusion which can be found in many locations throughout the Canadian Shield (see Figure 6-4). These formations contain little or no circulating ground water, have no known mineral value, and have remained stable, exhibiting few joints or fractures since they were formed over two billion years ago. Granite is, however, a brittle rock. At present we possess inadequate knowledge to ensure the integrity of the rock at the comparatively high temperatures generated by the radioactive waste materials, or under pressures from deep drilling and construction of the depository itself.

Rocks which were formed during volcanic ashfalls are called tufaceous rocks. Basalt is one such rock. Where the volcanoes have been active for long periods of time — hundreds of millions of years — as in British Columbia and the Yukon, and perhaps the Canadian Shield, the rocks are highly crystalline, and have an excellent ion exchange capacity. Water entering such a depository would be unlikely to carry radioactive wastes to the surface. However, much more research is needed. The effect of intense heat over long periods of time on the host rock is largely unknown. It has been suggested that faults may occur in the rock, or that the rock may experience "thermal fatigue". Unforeseen chemical reactions might also occur which would affect the containment of the wastes in the depository.

The materials used as packing and/or backfill for a deep repository could enhance the characteristics of the host rock favourable to long term containment. For example, bentonite clay, which is formed from the decomposition of volcanic ash, has a high sorption capacity and good ion exchange properties. Shale has similar characteristics. Furthermore, a mixture of quartz sand and bentonite, which is being considered by the Swedish nuclear industry because of its low permeability, seems to be a good prospect. Magnesium oxide has also been suggested because, in the presence of water, magnesium hydroxide is formed and would fill the space and prevent water from reaching the container.

The container surrounding the spent fuel or other highly radioactive waste is very important in that it provides the first barrier to the release of radioactivity to the biosphere. The container must be exceptionally strong (i.e. able to withstand an earthquake or the internal buildup of gases), and it must be non-corrosive and non-leachable.

Atomic Energy of Canada Limited has carried out extensive research on the fixation of liquid radioactive wastes from reprocessed spent fuel in a glass matrix, using nepheline syenite glass. In preliminary testing, this glass has indicated very low leaching rates. The other type of glass which could be used is borosilicate glass. However, the problems of producing a homogeneous, unfractured glass matrix remain. In addition, no process exists which would guarantee that the volatile radio-isotopes would not escape at the melting temperature required to fuse the wastes in glass. Once the material is embedded in a glass matrix, the temperature must not be allowed to rise too high, since higher temperatures accelerate the rate of leaching of glass. Fusing the spent fuel in base metals such as lead is also being investigated by AECL because of the low corrodibility of the material. For the same reason, the Swedish power industry is proposing the use of canisters made of titanium and lead.

A novel process has been developed in Sweden by ASEA, a manufacturer of electrical and mechanical equipment. The method uses hot isostatic pressing to produce a bottle-like container which, it is claimed, will be insoluble and non-corrodible for a period of one million years; it will be stronger than any existing rock. The spent fuel bundles would be encapsulated directly in these bottles, which could be made from either aluminum oxide or copper.

The depth of burial of the wastes is another

major question which remains to be answered. Three important factors are:

- *water flow*: water flow decreases with depth;
- *permeability*: permeability decreases with depth, and cracks tend to self-seal;
- *ion exchange*: there is greater ion exchange with rocks at greater depths, reducing the chance of water carrying radioactive materials to environmental pathways.

The question which must be addressed, therefore, is "how deep should the wastes be buried to maximize the benefit from these three factors?" AECL endorses the conclusion of the Hare report that a depth of 1000 metres is probably the most appropriate. At about 800 to 1000 metres the pressures would be sufficient to create an essentially homogeneous rock formation. At depths approaching 2000 metres, however, the problems of excessive heat will be encountered; at these depths, the temperature would be approximately 15°C above ambient temperature. In addition, there may be a problem of rock bursting. Arguments have been made both for deeper (from 2 km to 20 km) and shallower (300 metres) burial, on grounds respectively of safety and economics. Clearly, at present, knowledge is inadequate to make the optimum decision, but studies are continuing.

Social, Environmental and Economic Criteria

Dr. Uffen noted in his study that "The evaluation of social, geographic and economic criteria is not so well documented, despite the fact that these may be the crucial criteria." He lists the following criteria, which we agree with, for consideration in site selection:

The site should:

- be remote from densely populated areas;
- be compatible with present or future development of agriculture, forest products, hunting, fishing, quarries or sand pits;
- be compatible with water reservoirs, parks and recreational areas;
- respect legitimate local interests such as native rights, cottage owners and tourist resorts;
- be accessible by road and railway for heavily loaded vehicles;
- be capable of adequate security against trespassers, saboteurs or terrorists;
- have suitable land for employees' accommodation in a camp or small village;
- be suitable for the establishment of a processing plant for the "fixation" (immobilization) of the used fuel bundles;
- be in Ontario, preferably on Crown land, in a region where local opposition would be minimal;
- conform to all provincial, federal and applicable international regulations established by law;
- be owned by the federal government but operated jointly by agencies of the provincial and federal governments;
- be paid for by the major users, i.e. the electric utilities (e.g. Ontario Hydro).

Retrievability

Earlier in this section we raised the question of the retrievability of spent fuel. If solar energy and other alternatives such as fusion energy do not live up to present expectations, within the next fifty years a situation may develop in Ontario in which the reprocessing of CANDU spent fuel might be economic and desirable. Hence the dilemma: on the one hand effective ultimate spent fuel disposal is environmentally optimum, but on the other hand, if future generations need the energy available in the spent fuel, the retrievable option is clearly preferable. We believe that research should be pursued vigorously bearing both options in mind.

Conclusions

Our general conclusions (as well as those of the Hare and Uffen Reports) relating to radioactive waste management in general, and to ultimate waste disposal in particular, are given in Table 6-6.

Notwithstanding the level of optimism discernible in virtually all major reports relating to the disposal of spent fuel, we have several reservations. For the most part these relate to social and ethical concerns. For instance — where will disposal sites be located in the province? — will they be acceptable, on health, environmental and ethical grounds, to people living in the vicinity? We are aware, of course, of the ongoing research programme in which AECL and the Geological Survey of Canada are collaborating in the identification of suitable disposal sites in Ontario. But we are

concerned that an effective public educational programme is not being undertaken, and that information relating to the search for a suitable site, and the procedures being adopted, is not being published sufficiently widely. (The uranium refinery tailings problems at Port Hope will probably remain in people's memory for many years.) The first step must surely be to obtain the confidence of the public through full disclosure of all relevant information. The importance of this cannot be overemphasized.

In spite of the high level of confidence in the feasibility of the geologic disposal of spent fuel, expressed in the major reports referred to above, recently there have been more cautious appraisals of the problem. In particular, a group of United States Geological Survey geologists and, independently, a panel of eminent earth scientists have concluded that, at present, there is an inadequate scientific basis upon which to build the technology of high-level radioactive waste disposal. The panel, which reported to the United States Environmental Protection Agency, stated:[36]

> We are surprised and dismayed to discover how few relevant data are available on most of the candidate rock types even 30 years after wastes began to accumulate from weapons development. These rocks include granite types, basalts, and shales. Furthermore, we are only just now learning about the problem of water in salt beds, and the need for careful measurement of water in salt domes.

This expert opinion suggests that in the United States, there is urgent need for basic scientific research in the field rather than a plethora of paper studies. However, the extent to which the same criticism applies to Canadian work is problematical. Indeed, some field investigations are already in hand. Furthermore, because of the highly stable nature of the plutons in the Precambrian Shield, it is possible that Canada is in a stronger position than the United States to handle high-level radioactive wastes.

As in the case of the environmental problems associated with uranium mill tailings, we have concluded that an independent panel of internationally recognized geologists and geophysicists, reporting to the AECB, should review progress in the spent fuel disposal research and development field, and should report at about two or three year intervals. (Note that this panel corresponds to the Uffen "Advisory Council" — see Table 6-6.) The whole nuclear programme should be reassessed in the light of the panel's evaluation. Should Canada take a leaf out of Sweden's book?

- In April, 1977, the Swedish Parliament passed a law which stated, in effect, that no new nuclear power units could be put into operation unless the owner could prove that the waste disposal problem had been solved in a completely safe way.

We believe that the present is not an appropriate time to follow Sweden's lead (note that Sweden is better endowed with hydroelectric facilities and potential than Ontario). Nevertheless, if the "panel of independent experts" expresses dissatisfaction with the progress in spent fuel disposal research and development made, say, by 1985, a moratorium on new nuclear construction might be justified.

Reactor Decommissioning

It is anticipated that the economic lifetime of a nuclear reactor will be between thirty and forty years. What happens then? Because various components of the reactor, especially in the core, will remain highly radioactive for several years, special steps must be taken. The first of these is to remove the spent fuel from the core, the spent fuel in the storage bays, and the heavy water from the calandria and the cooling circuits. The radioactive inventory remaining is about 10^7 curies; subsequently three options are open:

- *mothballing*: this involves leaving the containment and cooling systems intact after the final shutdown, and keeping the building under surveillance for at least fifty years;
- *encasement*: all readily removable parts and components which remain radioactive longer than the projected life of the encasement structure are dismantled and removed. The remaining radioactive components are sealed within the encasement structure. Monitoring for possible radioactive leaks would be required for many years;
- *dismantling and removal*: all radioactive material would be removed from the site and buried. Large components such as the calandria would be

cut into convenient sizes. All handling, cutting, compressing, etc. processes would be handled remotely. The resulting radioactive waste material would be treated as high-level wastes and deposited in the ultimate waste disposal facility.

Some experience has already been obtained by both AECL and Ontario Hydro in the handling and removal of highly radioactive components such as pressure tubes and calandria tubes. Furthermore, AECL has removed the cores of the NRX and NRU reactors. The cost of decommissioning and dismantling will obviously increase with the capacity of the nuclear plant. It is clear, also, that the decommissioning of a plant should be taken into account by designing reactors with this long term problem in mind.

Chapter Seven

The Economics of Nuclear Power

WITH assets of $11.4 billion, Ontario Hydro is second in size only to the Tennessee Valley Authority among North American electric utilities and to the major Canadian banks among Canadian corporations. It is a growing electric power system, with capital expenditures on new facilities amounting to $1.4 billion in 1977. Ontario Hydro's operating budget for the year 1977 is also impressive, with expenditures totalling over $1.65 billion — more than $200 for every man, woman and child in Ontario. All these expenditures are related directly or indirectly to decisions on the expansion programme. Just under 40 per cent of the operating budget represents "fixed" charges (depreciation and interest), resulting from past capital expenditure decisions, with most of the remainder being the costs of operating the system (for example, operation, maintenance, administration and fuel costs).

A portion of revenue from present customers is used directly for expansion of the power system. But most — 80 to 85 per cent — of the capital construction programme is financed through the capital markets. Net new long-term debt issued for Ontario Hydro in 1977 amounted to $1.1 billion. This will be recovered through future operating budgets when the additional facilities begin service. Most people have difficulty relating to billion dollar sums, but this tremendous investment nevertheless comes about because of individual decisions made by each one of us as power consumers in this province. For example, taking into account the cost of new generating facilities as well as transmission, distribution, and back-up capacity, the innocent purchaser of a $29.95, 1000-watt electric space heater causes Ontario Hydro to maintain an investment of as much as $1200 to supply that single appliance![1]

We deal in this Chapter with some aspects of the economics of the future electric system, and the role of nuclear power within that system. The six nuclear plants and three heavy water plants operating, or under construction, represent a major proportion of the current investment programme. Capital expenditures foreseen for the future system expansion programme are illustrated in Table 7-1 which shows the year-by-year expenditure for the LRF 48A generation plan (see Chapter 3) estimated in 1977. About 45 per cent of this total expenditure is on already approved projects, with the rest for the proposed "post-Darlington programme". The nuclear component represents almost $24 billion of the $30 billion ten-year capital expansion programme.[2]

Choice of the future generating mix is partly based on the comparative economics of available technologies. Because of the uniquely long lead times associated with large generating stations (up to 8½ years for design and construction alone, with further time for planning and site choice), economic comparisons of generating technologies require estimates of construction costs some ten years into the future, with estimates of operating costs for an additional thirty years beyond that. Although the judgement of experts in these matters is invaluable, all future costs, particularly those beyond a ten year time horizon, are unknown and high levels of uncertainty remain. Moreover, all questions cannot be reduced to dollar terms and narrowly drawn notions of economic cost should not be the deciding influence in the debate.

As a consultant conducting a cost comparison

Table 7.1 Ontario Hydro Forecasts of Capital Expenditures, by Type of Generation, 1977-1986

Millions of dollars	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	Total
Hydraulic	21	19	22	23	24	27	29	31	34	37	267
Fossil	159	176	382	474	489	481	396	342	442	643	3,984
Nuclear[1]	634	723	888	1,244	2,846	2,113	2,431	2,704	2,929	3,239	18,507
Total	814	918	1,292	1,741	3,359	2,621	2,856	3,077	3,405	3,919	22,758
Heavy water	313	235	249	139	93	105	41	29	5	12	1,221
Transformation, transmission, and distribution	312	340	307	287	348	461	603	638	594	615	4,505
Communications, retail, and administrative and service facilities	120	130	144	156	169	180	194	208	225	240	1,766
Total	1,559	1,623	1,992	2,323	2,725	3,367	3,694	3,952	4,229	4,786	30,250

1 Includes heavy water inventory.

SOURCE Ontario Hydro, *Review of System Expansion and Financial Plans*, LRF 48A (April 1977).

of nuclear and coal-generating stations stated to the Commission:

> After you have taken every kind of extension you could possibly think of, incorporated every environmental aspect that you can measure . . . and then come out with a figure that showed that coal was still 35 to 85 per cent more expensive per kilowatt generated than nuclear, then the qualitative question is, is it worth it? Does society feel, having put a number on everything that can be measured, that cheaper electricity for nuclear [makes it] worth having nuclear around . . . The role of the economist is just to point out, here are the economic costs of everything that I can measure. Now it is up to society to decide.[3]

First however, we have to see where the traditional cost comparisons lead us, to which we now turn.

The Comparative Costs of Nuclear Power

Comparisons of the relative merits of alternative energy technologies are best conducted on a full fuel cycle basis — from exploration and mining through to ultimate station decommissioning and waste disposal. The nuclear power programme requires "front-end" capital expenditures for exploration, opening uranium mines, milling and fuel fabrication. The heavy water programme requires particularly significant capital commitments. Of the $30 billion forecast expenditures between 1977 and 1986 in the LRF 48A plan, over $1.2 billion was for heavy water plants and over $4.5 billion for heavy water inventory. Investments at the "back-end" of the nuclear fuel cycle must also be made for spent fuel management, irrespective of the extent of the future nuclear programme. It has been estimated that a spent fuel management programme could cost $600 million over fifteen years. Preliminary estimates by AECL suggest that a programme to demonstrate both fuel recycling and spent fuel management would require up to $2 billion (1976$) to the end of the century.[4]

However, a coal-based power programme has major front-end costs also. For example, the capital costs involved for transportation alone in bringing western Canadian coal to Ontario Hydro's power stations are estimated at $422 million, of which Ontario Hydro's share for railroad and coal blending equipment is $79 million.[5]

The Commission has not, to date, received a complete accounting of these front- and back-end costs but we expect to obtain more information about them during our "total systems" hearings scheduled for October 1978.

We concentrate in this report on the costs of generating stations, with capital costs of other portions of the fuel cycle considered only as they affect a single station. In discussing potential additions to Ontario Hydro's system we will deal, as much as possible, with "marginal" costs (costs of adding one more unit of generating capacity or of producing one more unit of electric energy).

Of the technological alternatives in prospect for the late 1980s and 1990s, CANDU-nuclear and coal are the major realistic options for large-scale generation of electricity in Ontario. Assuming that an acceptable means will be found to dispose of spent fuel, both can be considered proven technologies with costs that can be projected from past experience. As noted earlier, Ontario Hydro proposes a 2:1 nuclear-coal mix with nuclear used for base load purposes and coal for intermediate load; however, different proportions are technically possible. Therefore, the assessment of the relative economics of coal and nuclear generating stations for differing modes of operation is highly relevant.

The costs of generating electric power divide naturally into capital or "fixed" costs, and "variable" (operations, maintenance and fuel) costs. These costs are affected differently by the level of plant output. Because fixed costs must be recovered over the lifetime of the plant, lower energy output means recovery of the same cost over a smaller output, and hence a higher cost per unit of electricity. Fuel costs, by contrast, vary with level of operation and are consequently less per unit with lower output. Generating stations with high capital costs and low fuelling costs will therefore be most economic at high capacity factors, and those with low capital cost and high fuelling cost at low capacity factors. This is well illustrated by the following frequently cited comparison. In the late 60s and early 70s Ontario Hydro brought into operation two 4 × 500 MW unit stations — Pickering A,

Table 7.2 Comparison of Total Unit Energy Costs in a Coal and a Nuclear Generating Station[1]

Cost Component	Pickering A: nuclear (1976 mills/kwh)	Lambton: coal
Capital	4.4	1.6
Fuelling	1.2	10.8[2]
Operation and maintenance	1.8	1.0
Heavy water upkeep	0.3	
Total unit energy cost	7.7	13.4

Table 7.3 Comparative Costs[1] of Generating Electricity, Fossil, Hydro, and Nuclear Technology, 1976

	Generation cost		Transmission and distribution cost[2]		Fuel cost		Total cost	
	($/kW installed)	(Mills/kWh)	($/kW installed)	(Mills/kWh)	($/unit)	(Mills/kWh)	($/kW installed)	(Mills/kWh)
James Bay hydroelectric	691	12.47	560	11.02	–	–	1251	23.49
Gull Island hydroelectric	412	7.94	746	15.69	–	–	1158	23.63
Nuclear[3]	739	14.17	332	6.11	$110/kgU	3.55	1071	23.83
Coal-fired	375	7.19	332	6.11	$35/tonne	12.00	707	25.30
Oil-fired	308	5.90	332	6.11	$11.85/bbl	16.93	604	28.94
Gas-fired	308	5.90	332	6.11	$1.50/mcf	13.50	640	25.51

1 Both are assumed to be operating at 87 per cent capacity. 2 Based on 1976 stock of coal at the station.

SOURCE Ontario Hydro.

1 Costs include interest during construction.

2 Delivered costs assume Ontario loads; unit sizes for fossil and nuclear plants are 750 MW.

3 Nuclear capital cost assumes $97 per kilogram heavy water; nuclear fuel cost includes 1 mill per kWh for waste management, increased safety and environmental measures, and R & D.

SOURCE H. Swain, R. Overend, and T. A. Ledwell, *Canadian Renewable Energy Prospects*, (Ottawa: Energy, Mines and Resources, Canada, 1978).

which was nuclear, and Lambton, which was coal-fired. If each had been operated at 87 per cent of theoretical capacity, appropriate for base load (and the rate achieved by Pickering), a comparison of total unit energy costs in 1976 would have favoured nuclear generation by a wide margin (see Table 7-2).

On the other hand, at a capacity factor of 35 per cent, appropriate for intermediate load, the coal station would be more economic than the nuclear. It should be noted, however, that the Pickering and Lambton stations were constructed during a period of relatively low rates of increase in capital costs and brought into operation in a time of relatively high increase in fuel costs. The cost comparison of the early experience with the two stations is therefore exceptionally favourable to the nuclear station.

A similar comparison of total unit energy costs for generating stations to be brought into service in the mid to late 1980s would likely be less favourable to nuclear power because of predicted higher increases in capital costs and a slowing in the rate of increase in fuel costs. Indeed, initially, the total annual costs per unit of electricity could be about the same. One recent analysis by Energy, Mines and Resources Canada of the relative costs of electricity generation for plants ordered in 1976 (Table 7-3) indicates comparable costs for nuclear and large-scale hydraulic electricity delivered to Ontario loads, and higher costs, by about 12 per cent, for fossil-fired electricity. (Nuclear, specifically, is shown to have a 6 per cent cost advantage over coal.) However, nuclear and hydraulic technologies, having high capital costs and low operating costs, are less susceptible to inflation once constructed. Therefore, one would also expect a year-to-year comparison of total unit energy costs for nuclear and coal stations, ordered today for mid 1980s in-service dates, to be increasingly favourable to nuclear, because costs for the latter are relatively "inflation-proof", whereas the costs of "coal electricity" would tend to keep pace with increases in the price of coal.

A useful supplement to a total unit energy cost analysis, in a particular year, are cost comparisons for generating stations on a "life-cycle" basis. Figure 7-1 shows Ontario Hydro's life-cycle comparison of 4 × 850 MW coal and nuclear stations brought into service in the late 1980s. The comparison assumes base load operation and all cash flows are discounted at 10 per cent.

Capital costs, which appear in Figure 7-1 at zero years in-service, can be seen to comprise almost 60 per cent of the lifetime expenditure for a nuclear station as compared with only 15 per cent for a coal station. Discounted cash flow curves illustrate, in a dynamic way, the effect of relative capital-intensity on the lifetime costs of the two options. Because of the higher capital costs of the nuclear station its cumulative discounted cash flows are higher than those for the coal station in the early years. However, during the thirty-year assumed operating lifetime, the much higher coal fuelling costs cause the cumulative costs of the coal station to "catch up" and then to exceed those for the nuclear station. The crossover occurs after nine years and the cost advantage of nuclear power over its lifetime is about 65 per cent at a capacity factor of 77 per cent. This analysis is based on certain assumptions as to the major cost components, which we will consider separately.

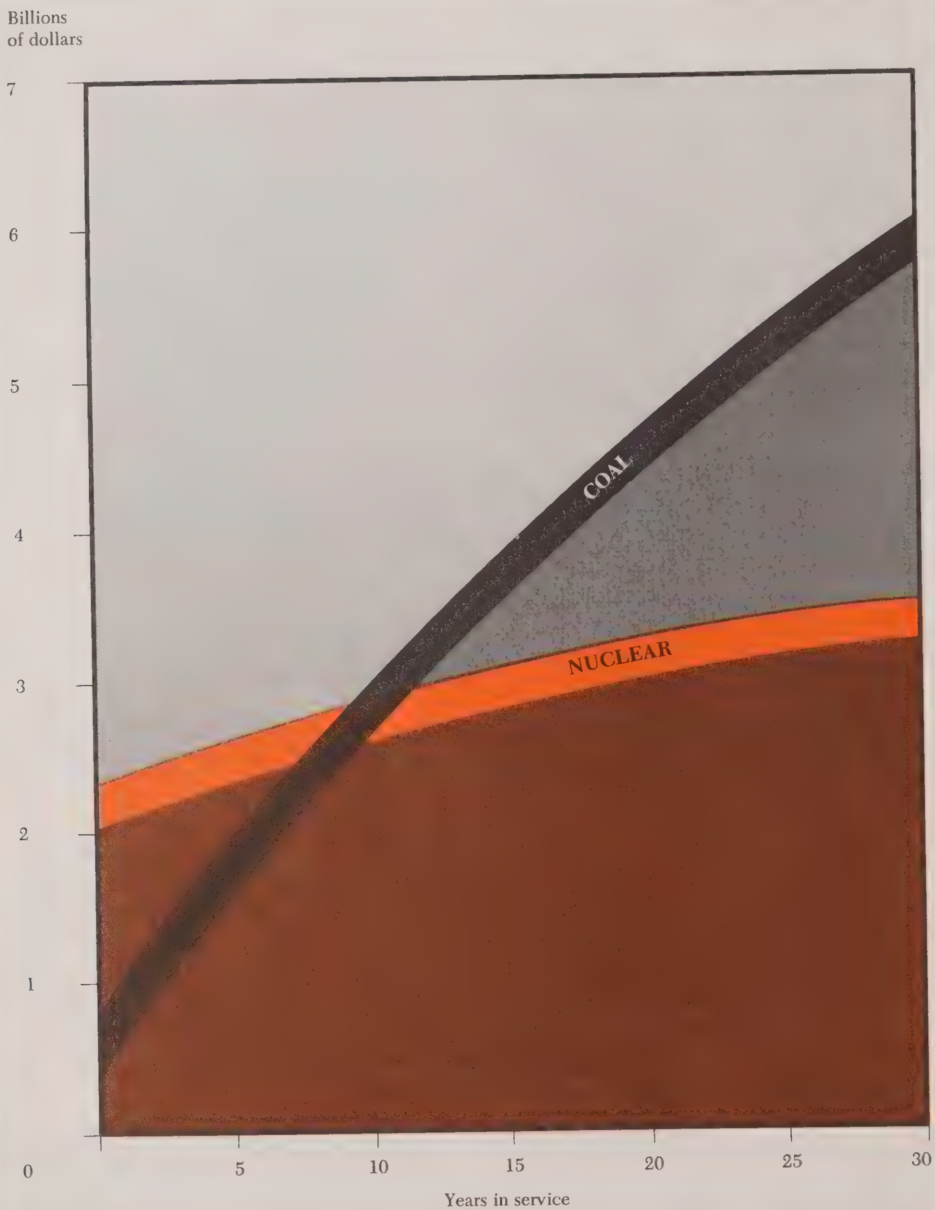
The Major Cost Components

Capital Charges

Because capital costs (and associated interest charges) comprise the majority of lifetime expenditures on nuclear stations, the factors affecting capital cost estimates are a matter of key concern (see Figure 7-2).

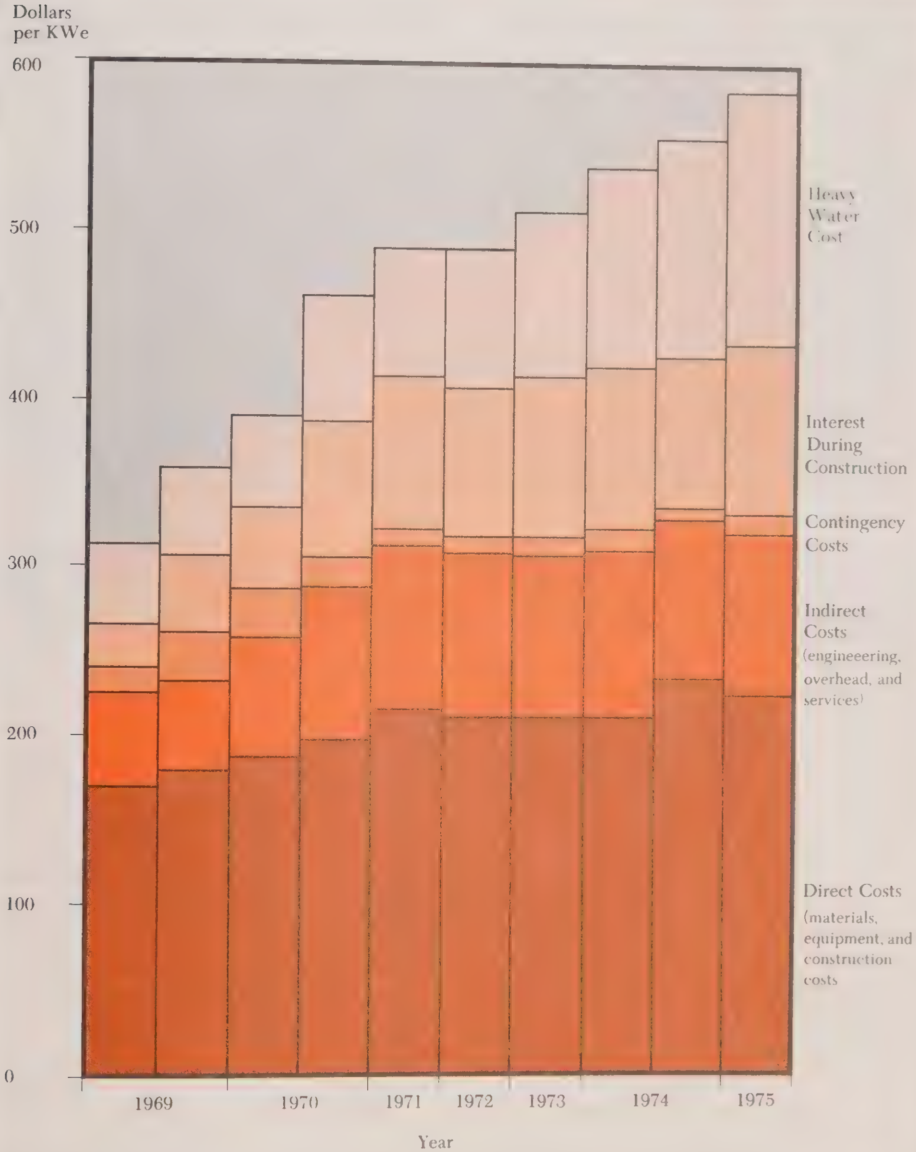
Siting decisions can substantially affect the cost of nuclear power plants. Costs vary from site to site due to differences in seismic criteria, the natural and physical environment, and accessibility of cooling water supplies and other facilities. These differences may be substantial; for example, it was suggested that a move to seismic zone 2 could increase capital costs by up to 5 per cent.[6] The construction of several units on a single site can reduce their total costs. Ontario Hydro uses four-unit modules the savings for which, over single-unit stations, have been estimated at 15 per cent.[7] The utility

Figure 7.1 Total Annual Costs of 3400 MW Coal and Nuclear Generating Plants, 1969-1975



SOURCE Ontario Hydro submission to RCEPP, March 1978, Exhibit 328-2, p.7.

Figure 7.2 Changes in Projected Capital Costs of the Bruce A Generating Station, 1969-1975



SOURCE D. C. Anderson, "Comparative Electrical Generation Costs," paper presented to the Sixteenth Annual International Conference of the Canadian Nuclear Association, Toronto, June 1976

Table 7.4 Forecasts of the Escalation of Coal and Nuclear Generating Stations Capital Costs

Year	Coal		Nuclear		GNP Deflator	
	(Index)	(per cent)	(Index)	(percent[2])	(Index)	(per cent)
1976	100.0	-	100.0	-	100	-
1977	108.2	8.2	109.4	9.4	106.0	6.0
1978	117.9	9.0	118.7	8.5	114.0	7.5
1979	129.1	9.5	129.4	9.0	123.1	8.0
1980	139.5	8.0	141.0	9.0	131.7	7.0
1981	151.3	8.5	153.0	8.5	140.2	6.5
1982	162.7	7.5	165.3	8.0	150.8	7.5
1983	174.1	7.0	177.6	7.5	159.8	6.0
1984	185.4	6.5	190.1	7.0	169.4	6.0
1985	197.4	6.5	202.4	6.5	177.9	5.0
1986	210.3	6.5	214.6	6.0	186.8	5.0
1987-2016	-	6.0	-	6.5	-	5.0

1 Excludes interest charges.

2 Includes one-half initial fuel charge.

SOURCE Based on data from Ontario Hydro.

also intends to duplicate stations at the same site, as at the Pickering and Bruce sites.

In general, capital costs have been increasing because of escalation in design and construction costs as well as increases in interest costs, heavy water costs, costs of meeting regulatory and environmental requirements, and costs of acquiring sites. Cost escalation for the major components (materials, equipment, labour, engineering, and interest charged over the construction period) has been unusually high over the past few years. For example, Pickering B, a station very similar to Pickering A, under construction on the same site after a ten-year interval, is expected to cost almost three times as much as Pickering A when escalation is included. (In constant 1976 dollars, however, the later station is projected to cost $20 less per kW, reflecting real savings in engineering design and common facilities costs.)[8]

Ontario Hydro's current estimates of generating station escalation (based on a representative "basket" of materials, labour etc. but excluding interest) are given in Table 7-4. Because the rate of increase of generating station costs is projected to decrease over the next few years, both the coal and nuclear stations' costs are expected to more than double by 1986. The 1985 $/kW costs are about $730/kW for a hypothetical 4 × 750 MW coal station as compared with $1,500/kW for a 4 × 850 nuclear station (Darlington).[9] Ontario Hydro's economists suggest that capital costs of the nuclear stations will continue to increase at a somewhat faster rate than coal stations beyond 1987.

Interest during construction accounts for about one-quarter of the total capital cost of stations planned for in-service dates in the mid 1980s. Interest rates have been high recently, but are predicted to decrease slightly in the early 1980s.

The initial heavy water charge comprises an additional one-fifth of total capital costs of a CANDU nuclear station. Production problems with the prototype Bruce heavy water plants, together with unanticipated cost overruns, resulted in heavy water costs contributing more than proportionally to the increases in the projected capital costs of the Bruce A nuclear station (see Figure 7-2).[10]

Bruce Heavy Water Plant (HWP)A came into service in June 1973. Bruce HWPs B and D are expected to come into service in December 1979 and July 1981, respectively. The expected capital cost of the three plants is $1.7 billion. Their potential annual production of approximately 2000 Mg D_2O could supply almost 2200 MW of nuclear capacity annually if 850 MW units were to be installed.

As of August 1978: Bruce HWP B is more than 95 per cent complete while Bruce HWP D is over 40 per cent complete. The demonstrated capacity of Bruce HWP A is 100 kg/hour. Operating at 100 per cent capacity the annual production from each plant would be 880 Mg D_2O. According to Ontario Hydro's estimates, the annual dependable supply from each plant is 550 Mg D_2O, the expected supply is 640 Mg D_2O and the "optimistic" supply is 700 Mg D_2O. The 1976 and 1977 capacity factors and output for Bruce HWP A were 91 per cent and 800 tonnes and 74.5 per cent and 600 tonnes, respectively.

The demand for heavy water by Ontario Hydro consists of central inventory demand for reactors being commissioned and make-up demand for losses during operation. Commissioning requirements per MW decrease with increasing reactor size. Inventory reserve of 300 Mg is maintained for the Ontario Hydro system. The annual loss during operation is about 5 Mg/year for each nuclear unit.

In 1976, when Ontario Hydro cancelled Bruce HWP C for economy reasons, this utility predicted that a tight supply situation would develop within a few years. However, the output of Bruce HWP A has been much higher than expected, the actual heavy water losses of nuclear units in operation have been lower than expected, export sales of CANDU reactors have not materialized, and the in-service dates of some of Ontario Hydro's projected nuclear stations have been deferred. The heavy water shortfall originally anticipated will probably become a surplus.

Bruce HWPs A, B and D could supply a nuclear programme of almost 50,000 MW by the year 2000. Bruce HWPs A and B together could supply a 30,000 MW nuclear programme. Bruce D appears to be superfluous to Ontario Hydro's probable requirements.

Ontario Hydro's capital cost estimates assume

no further major design changes due to regulatory requirements. It is likely, however, that a more rigorous regulatory environment would have a relatively larger impact on coal station costs than on nuclear, because nuclear stations are now designed to limit radioactive releases to an "as low as reasonably achievable" standard, whereas coal stations do not as yet incorporate all technically feasible air emission controls. For example, a decision by the Ontario Government to require the use of flue gas desulphurization equipment or "scrubbers" to reduce sulphur emissions from coal-fired power plants, as proposed by some participants in our hearings, could increase the capital costs of such stations by up to 25 per cent.[11] Therefore, despite the probable continuing upward pressures on nuclear plant costs, we believe that these costs when compared with coal plant costs will not significantly affect the lifetime cost comparison.

Operating Costs

Associated with the ongoing operation of a nuclear station are operations and maintenance (O&M), heavy water upkeep,[12] and fuelling costs. With heavy water up keep included, O&M costs for 850 MW nuclear stations are estimated by Ontario Hydro as almost 40 per cent higher than for coal stations of the same size. In at least one respect, future nuclear O&M costs may turn out to be underestimated, since it is probable that additional security requirements will become necessary. O&M costs can also be affected by unexpected maintenance or repair procedures. An example is the retubing required for units 3 and 4 of Pickering A. Partial retubing, because of this condition, may be necessary for units 1 and 2 of Pickering A, and for three similarly designed units of Bruce A. This work would require reactor shutdowns from six months to one year. This particular problem is not expected to recur in subsequent nuclear stations.

The costs of both coal and uranium fuel are dependent on world prices, on Ontario Hydro's success in using its considerable buying leverage to negotiate better than world prices for its fuel supplies, and on the uranium and coal policies of both the federal and provincial governments.

Uranium availability and prices will be discussed in more detail in Chapter 9. World spot uranium prices have risen by about a factor of ten since 1973. Fortunately, through forward contracts, Ontario Hydro has been able to keep its uranium cost increases, during the past four years, to approximately 11 per cent per annum. Some expert opinion foresees tight but adequate supplies of uranium and little or no price increase in real terms (i.e. fluctuation around $130/kg U in 1978 dollars). Others, including a consultant to Ontario Hydro, foresee a continuing upward price trend, though at more moderate rates than recently experienced. Contracts signed with Denison and Preston Mines assure Ontario Hydro of more than sufficient uranium for the thirty-year operation of existing and committed reactors.

Coal prices paid by Ontario Hydro have also leaped dramatically, virtually tripling in the five-year period since 1972 from $13/tonne to $38/tonne. Future upward price pressure on coal could result from less-than-expected productivity gains in eastern U.S. mines or success on the part of the Alberta government in pushing coal prices to parity with crude oil prices.

The life-cycle coal-nuclear comparison discussed previously is based on the use of U.S. coal. Because of transportation costs, coal from Western Canada is 40 to 50 per cent more expensive than U.S. coal.[13] Clearly, a nuclear station's lifetime computed cost advantage would be increased if the higher costs of western coals were assumed in the analysis or, indeed, if the capital costs (of a coal station) reflected the additional costs of specially designed boilers to burn the high ash western coals. The comparison is also based on Ontario Hydro's current economic forecasting "series" in which uranium costs escalate at twice the rate of coal costs, up to 1987, and at about the same rate thereafter. Higher rates of increase in uranium prices (than those estimated by Ontario Hydro) would not significantly increase the total cost of nuclear power relative to coal, since nuclear power costs are relatively insensitive to fuel cost. The fuel cost ratio of nuclear to coal per kWh generated is roughly 1 to 9; i.e., the $6.5 billion worth of uranium in the Denison and Preston contracts will generate as much electricity as $50 billion of U.S. coal or $65 billion of Alberta coal. In an analysis of life-cycle costs of thermal stations, Commission

consultants[14] could not postulate a reasonable uranium price increase that by itself would negate the cost advantage of nuclear-generated electricity. Consequently, we believe that future relative fuel price trends seem likely to have the effect of increasing lifetime costs of coal-generated electricity relative to those of nuclear electricity.

Lead Times

It was noted earlier that the long lead times associated with generating stations make cost estimation particularly difficult. Ontario Hydro's estimates assume a design and construction lead time of 6½ to 8½ years for large nuclear and 5½ to 7½ years for large coal stations, with additional time required for planning and site-acquisition activities. An increase in the construction period can affect interest and escalation components. Because virtually all contracts with suppliers include a provision for escalation, any deferral of in-service date after components are ordered will increase the final cost. Similarly, delay at that time will increase the amount of interest accumulated during construction.

By contrast, delays at the pre-approval stage of public participation, environmental assessment and regulatory review, which currently contribute some 2 per cent to capital costs, do not directly affect project costs. If the planners underestimate the time spent on these activities, project costs will normally increase due to inflation. But during this pre-construction period no interest costs are being incurred, so it is not possible to say in advance that the delay will increase the plant costs. Although the increasing lead times for large stations cause system planning uncertainties, and are important in comparisons with decentralized or smaller scale options, we have seen no convincing evidence that they will significantly affect the comparative economics of large coal and nuclear stations.

Reliability and Performance

Because of their high capital cost, it is essential to the economics of CANDU stations that they be operated at high levels of output over their useful lifetimes. The CANDU reactor allows on-power refuelling and therefore higher availability than, for example, U.S. light water reactors. For the past two years the availability of Pickering A has been outstanding (see Table 7-5). In 1977, a comparison of capacity factors of reactors of greater than 500 MW showed that all four Pickering A units ranked among the top six in the world. However, the lifetime performance of the station illustrates the problems that can be expected with a highly sophisticated, but "immature", technology. For instance units 3 and 4 were shut down during 1974-1975 in order to replace cracked pressure tubes. The lifetime capacity factor of the station is consequently 77 per cent. On the other hand, the lifetime availability factors of Douglas Point and NPD prototype reactors are 58.5 per cent and 67.6 per cent respectively, over periods of between 10 and 15 years. Because of the relatively few CANDU reactor years of operation, it is difficult to estimate lifetime capacity factors. However, we consider it reasonable to assume that CANDU reactors will maintain base load capacity factors.

Economies of Scale

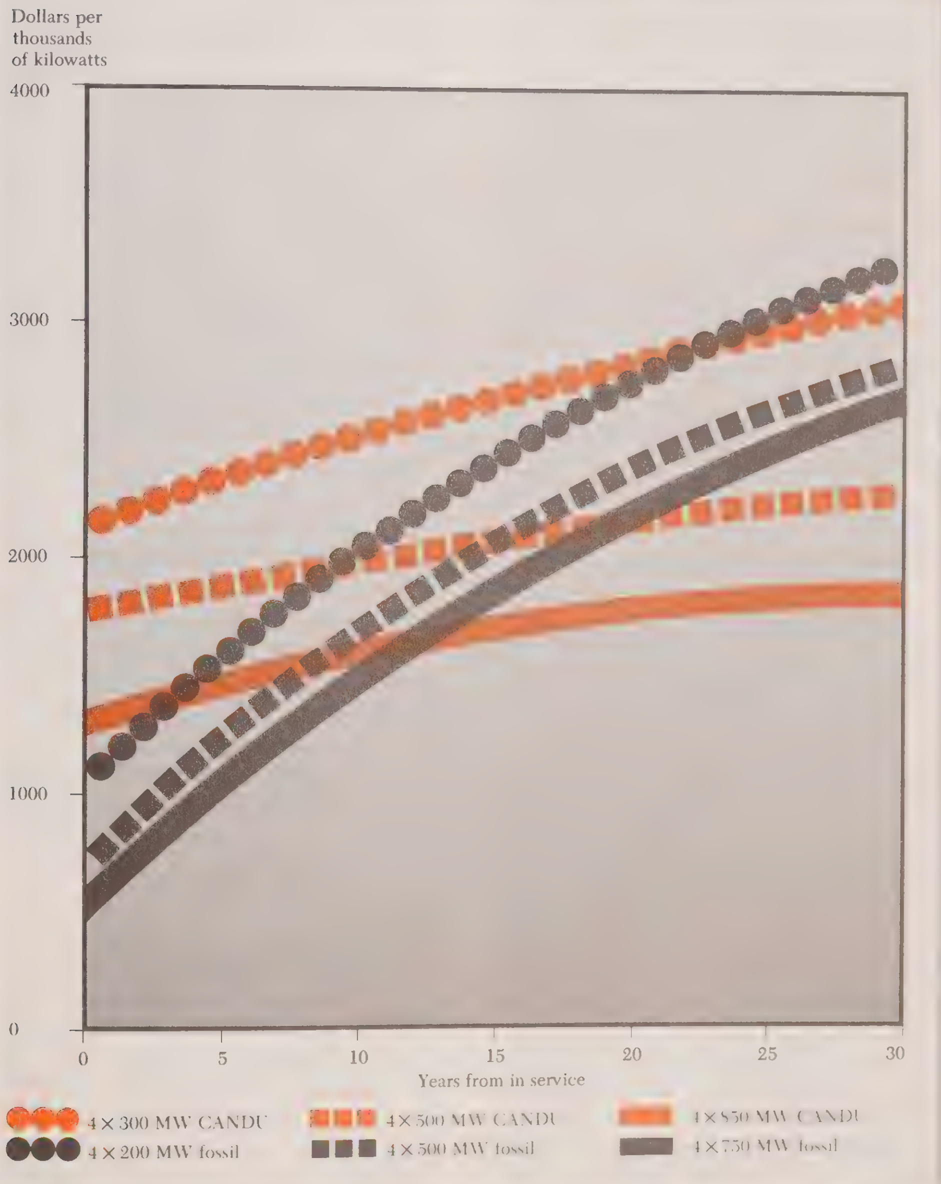
The evidence to date suggests that Ontario Hydro's decision to adopt the 750-850 MW unit size range for thermal generating units will result in significant scale economies. Conversely, a choice of 200 MW units results in a lifetime cost penalty, when an individual station is considered. However, this size of unit (200 MW) is appropriate for a small system, and is being considered for use in Ontario Hydro's West System. Figure 7-3 gives some hypothetical projections developed by Ontario Hydro which indicate that, up to a certain size, larger units are cheaper on a life-cycle basis than small units for both coal and nuclear stations. On a comparative basis, the lifetime economic advantage of a nuclear station is very small for the small units, but becomes more significant with increases in unit size. The crossover point at which nuclear stations become cheaper than coal stations is not reached, in the case of 200-300 MW units, until the third decade of operation, compared with a 15-year crossover for 500 MW units and 11 to 12 years for 750-850 MW units.

Table 7.5 Annual Capacity Factor of Pickering A, 1973-1977

	1973 (per cent)	1974 (per cent)	1975 (per cent)	1976 (per cent)	1977 (per cent)
Unit 1	92.5	72.0	80.2	92.8	85.5
Unit 2	69.0	88.4	86.0	93.2	90.9
Unit 3	85.1	42.7	57.5	93.9	95.6
Unit 4	90.1[1]	93.9	23.8	68.4	90.8
Average	83.4	74.3	61.9	87.1	90.7

1 For part of the year only.
SOURCE Ontario Hydro.

Figure 7.3 Life Cycle Costs of Coal and Nuclear Generating Stations for Different Unit Sizes



1 Discounted to year of first unit in service at 10 per cent annually, assuming a 60 per cent factor capacity.

SOURCE Ontario Hydro, Generation Planning Processes, May 1976.

A True Accounting for Nuclear Power Costs?

The nuclear industry points with pride to the production of comparatively low-cost electricity from the Pickering generating station and advocates inexpensive nuclear electricity as the cornerstone of Ontario's future energy strategy. But critics have argued that many significant investments in the front-end of the nuclear fuel cycle have not been fully recovered, that some future costs at the back-end of the fuel cycle have not been taken into account and that many costs of the nuclear programme have been borne by the Canadian taxpayer rather than the users (e.g. research and development costs). They argue that if all the costs of the nuclear programme were accounted for, nuclear power would lose much of its economic attractiveness. These include prospective future costs for security, decommissioning, irradiated fuel management, insurance and liability in the event of nuclear accidents, and "hidden" and "social" costs external to the utility.

Prospective Future Costs

Measures to increase the physical security of nuclear power stations against terrorists or saboteurs would be reflected in increases in both capital and operating costs for surveillance systems, extra barriers and additional staff. A consultant's study for the Commission has suggested that a security guard force totalling 34 additional persons would add $2.35/kW to the 1985 nuclear O&M cost of $12.41/kW.[15]

At the end of its operating life, a nuclear power reactor must be decommissioned. Ontario Hydro has traditionally assumed that the salvage value of materials, spent fuel, and, in particular, heavy water from a nuclear reactor would at least equal the costs for decommissioning, and consequently the costs of this activity have not been included in electricity rates. The assumption of a salvage value for heavy water assumes the continuance of a CANDU-type nuclear power programme beyond the expected thirty-year lifetime of the station. However, it was noted also that nuclear power plants might operate (and produce revenue) beyond their assumed thirty-year life.[16]

There can be no assurance of a market for heavy water after the expected thirty-year useful life of the current generation of nuclear plants, or of revenues from electricity sales from plants whose useful life exceeds thirty years. We believe, therefore, that it would be prudent to incorporate in current electricity rates an amount sufficient, on a sinking fund basis, to defray at least half the expected station decommissioning costs.

Several studies suggest that decommissioning costs will be a small fraction of total reactor cost. For example, an AECL study provided a representative estimate of $30 million for the dismantling and removal of a 600 MW reactor.[17] This study also noted that a $100 million sinking fund could be developed over thirty years by a 0.45 mills/kWh (1976$) annual surcharge on the price of electricity. A review, undertaken for the U.S. Congress, of the Nuclear Regulatory Commission's and the Energy Research and Development Administration's programmes for disposing of nuclear facilities cites costs of up to $40 million (1975$) for decommissioning "an average reactor".[18] And Ontario Hydro has suggested that decommissioning costs might be about 1 to 5 per cent of initial plant costs.[19] A dissenting view, however, was presented by Dr. Gordon Edwards who stressed that the above estimates are for "normal" decommissioning situations only and do not allow for improbable events such as reactor accidents.

Dr. Edwards also suggested that problems with the disposal of facilities and materials associated with the front- and back-end of the fuel cycle could prove more intractable and hence more costly than reactor decommissioning. To deal with such problems, a charge to cover clean-up of all radioactive wastes associated with the CANDU fuel cycle has been suggested. A "Nuclear Decontamination Fund" is provided for by Bill C-14[20] in recognition of the fact that significant costs may post-date the existence of companies whose operations caused the contamination in the first place. The development of such a fund would inevitably give rise to an increased cost for nuclear-generated electricity.

At present the prospective costs of the permanent disposal or management of spent CANDU fuel are not included in the price of electricity. Indeed, it will be virtually impossible to assign

meaningful costs to this activity until detailed geological and engineering studies have been completed. Ontario Hydro estimates (we were not informed as to the basis for these estimates) that such costs would add no more than 0.2 mills/kWh (1976$) to the cost of power.[21] Pending a firmer basis for establishing a proper charge, costs at least in the order suggested by Ontario Hydro should be added to the cost of power to create an appropriate sinking fund to defray future costs for spent fuel management and disposal.

The costs which might be associated with an improbable, but major nuclear accident (see Chapter 6) are impossible to estimate. The federal Nuclear Liability Act at present requires the operator of a nuclear installation to carry $75 million in third party liability insurance per installation[22] (see Chapter 12). Ontario Hydro's current premiums for this insurance are $815,000 per annum and are expected to increase to about $2.3 million in 1985. To the degree that the $75 million limit implies a promise on the part of the government to provide relief from consequences of a nuclear disaster beyond the coverage provided by the private insurance pools, there exists a subsidy to the power utility. For electricity to be properly costed it would be necessary to charge Ontario Hydro customers the imputed cost of the premiums that, in the absence of the government backstop, would presumably have to be paid to private insurers.[23] We, however, do not advocate the imposition of such a charge at this time.

"Hidden" Costs

The costs of public participation, site evaluation and environmental assessment, including public hearings, have been estimated to comprise 2 per cent of the capital cost of a generating station.[24] More difficult to assess are the "hidden" costs in terms of demands on government agencies and departments. Although some costs of obtaining government and regulatory agency approval are common to coal and nuclear stations, there are additional costs in the licensing of nuclear facilities and regulation of activities involving nuclear materials.

Research and Development

Nuclear research and development (R&D) costs are also largely "hidden" in the sense that they have been incurred by agencies other than Ontario Hydro and have not entered the cost of electric power. R&D funds already spent on the nuclear power programme are normally regarded as a "sunk cost" for purposes of economic evaluation. However, the magnitude of this "subsidy" of nuclear power should be taken into account when comparing the nuclear option to renewable energy prospects.

Nuclear R&D costs can be roughly estimated by reference to the budget of Atomic Energy of Canada Limited (AECL). Figure 7-4 shows AECL's R&D expenditures, which amounted to about $100 million in 1977 or 0.05 per cent of the Canadian GNP. (There has been a gradual shift of R&D effort since 1968 from AECL to other agencies; for example, Ontario Hydro has spent $15 million since 1971 on R&D related to a potential 1250 MW reactor.) The total historical $1.2 billion expenditure on nuclear R&D is equivalent to an expenditure of $70/kW on reactors now operating or committed, or 0.8 mills per kWh.[25]

If we assume only minor design changes in future first-generation CANDU reactors (this appears justifiable because of the excellent performance of existing units), only minimal R&D back-up will be required. However, AECL's current R&D budget includes a 40 per cent allocation for "new CANDU reactors" and "underlying and advanced system research", suggesting that expenditures on future first-generation CANDU reactors are ongoing, and that significant design changes may be forthcoming. Present indications are that if Canada develops a commercial CANDU based on an "advanced fuel cycle" (e.g. thorium-uranium-plutonium), the R&D costs might be in the order of $1.5 to $2.0 billion (1976$). Although we do not endorse this path, certainly not before the year 2000, we believe that the research should be continued — the possibility of an "advanced fuel cycle (thorium)" co-operative R&D programme between Canada and the United States might be particularly appropriate and should be explored.

Existing R&D expenditures on nuclear power are appreciably greater (indeed by a factor of 7)

Figure 7.4 AECL Research and Development Expenditures, 1955-1977

SOURCE J.S. Foster, "AECL Present and Future." Speech presented to the 15th Annual International Conference of the Canadian Nuclear Association, Ottawa, June 15-18, 1975

than those on renewable energy resources.[26] Bearing in mind the fact that nuclear energy will contribute a comparatively small proportion of the total primary energy needs of Ontario (and even less of Canada's) during the next twenty-five years (it was 5.6 per cent in Ontario in 1976), it is important that energy R&D funding priorities should be re-assessed. Conservation technology, wood and biomass energy, solar energy and wind energy are all fields which deserve considerably more R&D support on economic, social and environmental grounds.

But continued nuclear research is important, regardless of the extent to which nuclear power evolves in Canada. We stress, in particular, the urgent R&D needs of the "front-end" — e.g. the ultimate safe disposal of mill tailings, and the "back-end" — e.g. the ultimate safe disposal of high-level radioactive wastes.

Social Costs

Social costs for our purposes are those costs arising at any stage of the electric power programme which are external to the programme and are not included in electricity prices. They can include, for example, costs arising from damage to health, property or the environment. Although some of the more tangible of these costs have been estimated, social cost methodologies are poorly developed and the subject of much disagreement. However, some social costs have already been incorporated into Ontario Hydro power rates by, for example, decisions to install equipment to minimize environmental impacts, and by placing a surcharge on the cost of exported electricity to reflect the social costs of coal-generated electricity for export. This internalization of costs will undoubtedly continue as legislation or utility policies incorporate the concerns of society. However, the magnitude of these costs, and their relative impact on coal- and nuclear-electricity costs, are difficult to predict.

Lifetime Costs of Nuclear Power Plants

The large lifetime economic advantage of nuclear power for base-load purposes seems to be retained even when reasonable estimates of the prospective future costs discussed above are incorporated (although, as noted, many of the existing cost estimates are speculative).

An analysis, by two of our consultants, which incorporated several costs of the types considered above, has tested the effect of variations in the factors influencing coal and nuclear life-cycle costs. The study concluded:

> In general, combinations of high real discount rates, low capacity factors, substantial increases in the capital cost of nuclear vs coal stations, and significant increases in the price of uranium relative to coal are necessary to make coal competitive. Each of these factors alone cannot offset the cost advantage of nuclear power unless unrealistic values are adopted. . . . The results [of our study] unambiguously indicate that in terms of economic costs in Ontario, nuclear generating stations are substantially more attractive than coal-fired generating stations.[27]

We have concluded that CANDU units in the 850 MW capacity range are the obvious economic choice for Ontario Hydro's base load generation.

Ontario Hydro has proposed the use of 1250 MW CANDU units in order to capture further scale economies. An increase from 850 to 1250 MW would, by the utility's estimation, decrease unit capital costs and total unit energy costs by about 10 per cent (even when economic penalties because of lower estimated reliability of units in this size range are taken into account).[28] The utility has argued that the economies arise from the fact that the 1250 MW unit is designed to use as many standard components (from the 850 MW design) as possible, e.g. circulating pumps, pressure tubes, and boilers, so as to maximize the economies of scale relating to common plant facilities. A major exception is the turbine-generator; but Ontario Hydro's Director of Design and Development, Mr. W.G. Morison, expressed confidence that good competitive bids could be obtained on these (at some cost in terms of Canadian content) from two European and two U.S. suppliers.

Although Ontario Hydro stated that the very large U.S. reactors have demonstrated economies of scale, no detailed capital cost or operating experience data, in support of this affirmation, have been made available to us. Furthermore, U.S. reactor commitments do not indicate a strong trend to

the 1250 MW size range in the 1980s.[29] Few large scale reactors have reached their "mature" operating state. In the hearings, several participants argued that Ontario Hydro's limited experience with very large generating units provides insufficient proof as to the reliability of both nuclear and non-nuclear components.

Moreover, there appear to be some potential economies of standardization, particularly in regard to the review process. System aspects are also important; as noted earlier, smaller units may provide equal reliability with fewer megawatts than larger units. It appears that the full economic advantage of the 1250 MW unit requires a system size which, on the basis of the lower load forecast, will not be attained until the 1990s. For these reasons we are not convinced, on the evidence presented to date, that the 1250 MW CANDU reactors should be part of Ontario Hydro's system expansion programme before the turn of the century.

Even with appreciably lower capacity factors than those achieved to date, and with other assumptions unchanged, CANDU stations of the 850 MW size are still more economic, on a life-cycle basis, than coal stations. Indeed, the economic advantage exists down to average annual capacity factors of less than 55 per cent, i.e. in the range of intermediate load operation. However, the cross-over point is later and the lifetime cost advantage less. Furthermore, existing CANDU plants cannot readily be cycled to follow the ups and downs of the daily load curve. Accordingly, we believe that the need for additional nuclear capacity is dependent on the need for additional base load capacity. Indeed, we are aware that technological advances ("hard" or "soft" as the case may be) may lead to forms of generation sufficiently superior to CANDU reactors, in terms of operating flexibility, thermal efficiency or straight economy, to displace even current nuclear plants from base load operation.

It is particularly important, prior to committing further nuclear capacity, that the load forecast, and the likely shape of the system load curve, should be carefully reviewed to substantiate the need for base load capacity over the long term. If this review demonstrates that a continuing need for base load capacity is uncertain, or shifting load requirements appear probable, generating options which are more operationally flexible (such as fossil or hydraulic capacity) may be preferable to the nuclear option. For example, a larger proportion than the proposed (by Ontario Hydro) one-third coal, in the generating mix, could allow operation of coal stations, for temporary base load followed by subsequent use for intermediate or peaking purposes, and ultimately, perhaps retrofitting them to burn wood and waste.

An alternative scenario is one in which successful implementation of capacity management programmes (e.g. pumped storage) could raise daily and seasonal load factors such that the system could accept a two-thirds nuclear mix.[30] The Commission expects to hear more about these matters in the "total system" hearings. In addition to a suitable matching of capacity to load requirements, an analysis of system economics requires an assessment of economies of scale, station reliability as it affects the need for reserve capacity, economics of electric power and energy imports, and exports and other dynamic effects. Static comparisons of the costs of single stations are a poor substitute for assessing the discounted incremental costs of adding each type of plant in a full (thirty-year) system planning cycle. Because we believe that a life-cycle assessment of different generating technologies, within the context of the future power system, is essential, we defer our detailed comments on load and capacity characteristics and the consequent preferred system mix to the final report.

Costs on a system basis depend on the rate of system growth and the mix of generating plants. Ontario Hydro has pointed out, for example, that Pickering A has "saved" the power consumers of Ontario millions of dollars as compared with the cost to build and operate an equivalent coal-fired station. (This saving has been estimated at $32 per customer in 1977.[31]) However, total expenditures on the expansion programme are, and will continue for some time, to be higher because of the nuclear commitment. The utility informed the Commission that "an all-coal-fired programme would require less funds up to the early 1990s at which time the situation would be rapidly reversed and would result in an overwhelmingly large penalty in costs for an all-coal-fired case by

the year 2000, and an even greater penalty beyond that time.[32] The heavy front-end expenditures both to build the more expensive nuclear stations and to create the supporting nuclear infrastructure (e.g. heavy water plants) have placed upward pressure both on borrowing requirements and revenues to be raised from power rates.

Because Ontario Hydro has not provided the Commission with details of the impact on capital requirements and electricity rates of alternative (to LRF 48A) mixes of nuclear and coal generation, we are not in a position to comment on these matters at this time. However, the following preliminary observations on the timing of expenditures, as related to the need for funds from the capital markets and from electricity rates, may not be out of place.

The "Capital Gap"

Almost 85 per cent of Ontario Hydro's capital requirements is raised from debt markets, with repayment guaranteed by the Provincial Government — the rest is "internally generated", i.e., raised through power rates. Capital borrowing constraints have already occasioned adjustments to the planned expansion programme. In 1976, a perceived unsupportability of capital borrowings over the short term led the Provincial Treasurer to limit Ontario Hydro's borrowing for the period, 1976 to 1978, to a level well below that originally planned. (As noted in Chapter 2, this limitation, when combined with a desire to minimize power rate increases, made necessary substantial cutbacks in the planned medium-term expansion programme, with several committed projects, including nuclear stations and a third heavy water plant, deferred, and the fourth heavy water plant at Bruce cancelled.)

In the view of the Provincial Treasury, we have entered an "era of continuous borrowing constraint" in which capital availability must be a key element in the planning process.[33] It is necessary, therefore, to review continually the forecasts of the amount of capital available for Ontario and Ontario Hydro at optimal interest rates, and without using "risky" markets, that might jeopardize continued access to capital at the most favourable market rates. We note with approval that since 1976, the Office of the Chief Economist of Ontario Hydro has adopted the "stock adjustment" approach favoured by the Ministry of Treasury, Economics and Intergovernmental Affairs. This approach seeks to estimate, in as systematic a way as is possible in the always fluid capital markets, the amount of a given borrower's securities which the market as a whole appears willing to hold. These estimates are then compared to the capital requirements associated with possible system expansion programmes.

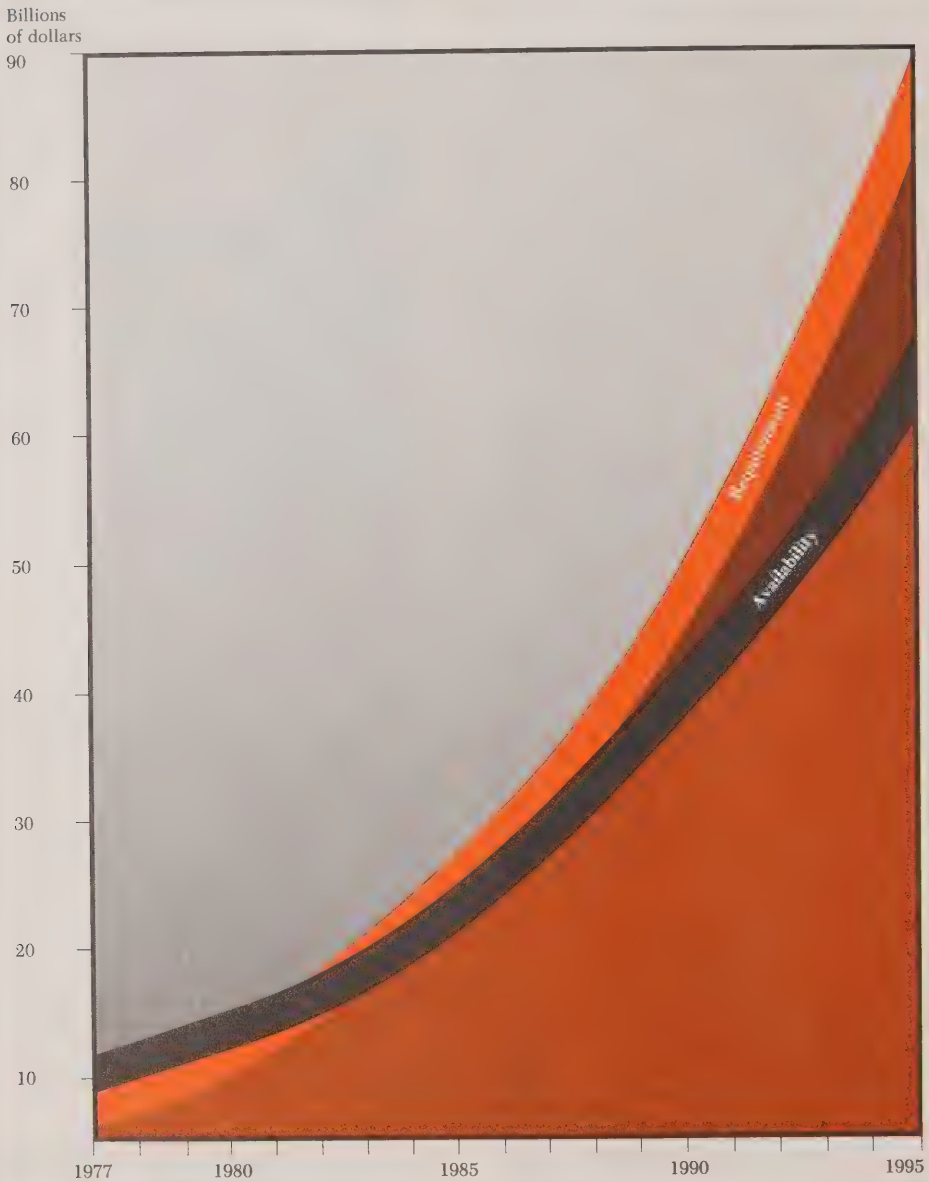
Figure 7-5 illustrates Ontario Hydro's May 1977 capital availability estimate and the capital requirements for the LRF 48A forecast plan under current financial assumptions and a policy of moderate rate increases. Commenting on the accumulating shortfall beginning in the early 1980s, Ontario Hydro reminded the Commission of the uncertainties of such projections, implying that the shortfall may not in fact materialize.[34] It should be noted, however, that the possible problem — although described by one Ontario Hydro document as occurring in the "very long-term" — falls within a shorter time horizon than used for the economic comparisons of the coal-nuclear stations discussed previously. Despite the uncertainties associated with such forecasts, we believe they can and should be used as indicators of the adjustments required well before mere problems turn into crises.

Several factors suggest that Ontario Hydro's estimates of capital available to the utility may be optimistic:

- the estimates are for public capital available to Ontario Hydro and the province. However, it is assumed that all the capital is directed to Ontario Hydro purposes. This will not be possible unless the province is successful in achieving, and maintaining, a budget sufficiently close to balance that it can provide for any net cash requirements from non-public borrowing, e.g. from federal pension, government employees' and teachers' pension funds;
- cumulative numbers assume that a surplus in any given year remains available in later years;
- there is substantial reliance on non-Canadian capital markets, with attendant risks of market closure or major foreign exchange fluctuations.

Because of this "downside risk" to capital availability estimates, and also because Ontario Hydro

Figure 7.5 Capital Requirements for LRF 48A Compared With Capital Availability, 1977-1995



SOURCE Ontario Hydro, Capital Availability to the Province of Ontario and Ontario Hydro, 1977-1995, March 4, 1977, Chart 3. Submission to RCEPP, March 1977.

itself acknowleges a potential capital shortfall as early as 1981, the possibility of capital shortfalls should be considered a "real" constraint to be addressed as an intregal part of the system planning process.

Under consideration by the Commission are some proposed solutions to this problem such as: taking action to broaden Ontario Hydro's access to capital markets, making some of the over $1 billion per annum from the various pension plan moneys available to Ontario Hydro; conservation or load management programmes aimed at reducing the expansion programme (especially the nuclear component); or increasing power rates.

Electricity Rates

The major interest of the customers of Ontario Hydro in these fairly esoteric matters stems from the eventual impact of capacity additions on electricity rates. As noted earlier, electricity costs are made up of fixed costs such as interest and depreciation, which are incorporated into electricity prices according to statute and accounting convention, and variable costs for fuel, operations, maintenance and administration, which are charged in the year incurred. It takes many years before a decision on a particular station type will be reflected in the cost of power, because all construction and interest charges are capitalized until the in-service date. Any net benefit from lower operating costs occurs even later. For example, if savings as a result of the decision to commit Darlington as a nuclear facility (rather than fossil-fuelled) materialize as predicted, these will not be reflected in electricity bills until the early 1990s.

In considering the capital gap, Ontario Hydro has suggested that, although increasing the proportion of fossil plant would reduce capital requirements in the short term, it would result in significantly higher electricity rates over the long term, because of the superior lifetime economies from nuclear plants. The utility argues that short term capital shortfalls could be offset by short term rate increases to provide extra revenue for financing system expansion.

Increased rates to defer a capital shortfall would, of course, somewhat delay the net savings to consumers accruing from the nuclear commitment. We believe that electricity rates should be increased only if no other acceptable means are available to close the capital gap. The appropriate level of capital to be raised from rates should be evaluated independently of any pressures created by the existence of a capital shortfall, by the requirement to maintain financial integrity, and by comparison of Ontario Hydro's financial indicators with those of similar electric utilities and competing energy corporations. From this latter perspective, it is clear that electricity in Ontario has in fact been somewhat underpriced relative to other jurisdictions (as Task Force Hydro concluded in 1972, and the Ontario Energy Board has reported on several occasions since then).

Increased rates can perform a dual role both in providing funds for growth in the system, and in restraining growth to manageable levels through the strong potential influence of price on the future demand for electricity. J.R. Downs has recently observed that: "By slowing the growth of demand, and promoting capital accumulation at the same time, pricing policy [based on marginal costs] might well perform its traditional role of resource allocation and thus help to avert the capital crunch projected for the 1980s. This is a consideration which will have to be addressed by the publicly owned utilities and their political masters."[35] Even without the element of scarcity pricing however, electricity is already a relatively expensive energy source for certain purposes, e.g. space heating, despite the benefit from the large low-cost hydroelectric component of the system. Electricity prices in other provinces, which are forced to rely on thermal power based on imported oil, are as much as two or three times those of Ontario. As noted earlier, it is apparent that no future energy source — including nuclear power — can be developed at costs similar to what was possible in the era of cheap energy.

Economic Analysis and System Planning

At the beginning of this Chapter we stressed that economic cost should not be given undue emphasis in the system planning process. Because of the uncertainty implicit in all forecasting, and the long time horizon of decisions, costs are unknown and

unknowable. They are also not independent of social and political priorities which affect the type of cost considered and the relative value assigned. Moreover, in the long term decisions necessary to electric power planning, issue has been taken with a key premise of cost-benefit models, namely, the assumption that future costs should be discounted (that is, assigned a lower value than present costs). One recent study noted:

> ...decision-makers are concerned that if we were to discount at a positive rate in a world of exhaustible resources, would we not condemn future generations to a world of scarcity? Or, if we were to invest in projects with uncertain environmental effects, the result for future generations could be even worse than scarcity. Frank P. Ramsey, in his pathbreaking work published in 1928, argued for a zero rate of discount; that is, not weighting the welfare of future generations less than that of the present one, and, more recently, Robert Dorfman of Harvard and others have suggested that in relation to things such as health effects, we should discount at a zero rate.[36]

Several participants at our hearings expressed similar views concerning the need to acknowledge future costs adequately.

Dr. Philip Hill, a consultant to the Commission, succinctly expressed the difficulties:

> Benefit-cost analysis applied to power system planning is critically dependent on major value judgements needed in weighing the costs and benefits of intangibles and the equity of future generations. . . . environmental damage are considered, social costs can be said to be negligible compared to generation cost. . . . But allowing for possibly high values which society may wish to place on the non-financial aspects of health and amenity losses, it cannot be said that the social costs of power generation are necessarily negligible, or should not play a role in system planning. What is needed is widespread public appreciation of all social cost implications, so that social values and preferences can be determined.[37]

We are aware, of course, that it is not possible to determine generally accepted dollar values for all social costs (many of which are elusive and judgemental). However, attempts at quantitative assessment help to focus attention on particular costs and benefits which are important to system planning decisions, and help in identifying major differences in value judgements.

Although Ontario Hydro's mandate to supply electricity at the "lowest feasible cost" often serves to focus discussion largely on internal economic efficiency, there are important issues beyond the utility's cost framework. In the following Chapter we move beyond "economic" costs to consider some socioeconomic costs and benefits, not all of which are quantifiable.

Chapter Eight

Social Impacts and the Status of the Nuclear Industry

QUITE apart from the value to Ontario residents and industry of access to the imputed lower-cost, more reliable electrical energy made possible by nuclear power, it was suggested during our hearings by nuclear industry spokesmen that the construction and operation of nuclear stations provide a major stimulus to the national and provincial economies, have a positive effect on the balance of payments and create significant employment opportunities.

Adequate testing of this proposition would require some fairly sophisticated economic modelling, to analyze the impact on the growth of the national and provincial economies of variations in the size and timing of Ontario Hydro's nuclear programme. We are undertaking studies of this kind in co-operation with Statistics Canada; these should throw some light on the question. We have also examined several U.S. studies, and noted some consensus that the benefits of a nuclear programme can be in the order of 1 to 2 per cent of GNP. But the Ford-MITRE study warns that

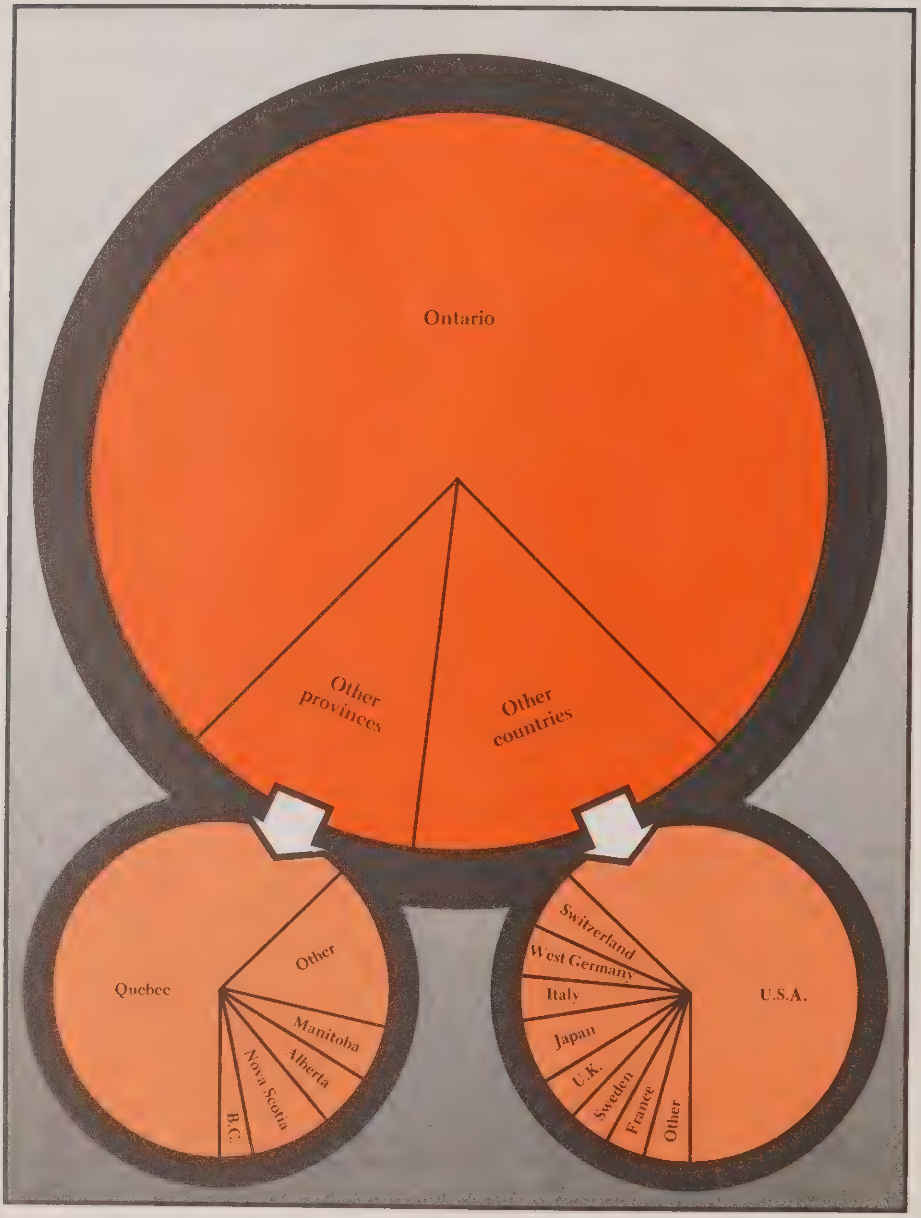
> ... since nuclear fission is only one among several energy sources and, for the next few decades at least, has no more than a small advantage over other high-cost energy sources, near-term actions on nuclear power can hardly be critical to society's economic future. It is as incorrect to argue that nuclear power is "needed" now to allow society to continue its development as it is misguided to hope (or fear) that society could be forced into some no-growth utopia if only the current nuclear program were abandoned. Energy costs are just not that important, and nuclear power will not do much to reduce them in any case.

Nevertheless the study concluded that unless fusion and solar energy are developed as an economic source of electric power, and unless a large scale coal programme proves environmentally acceptable, "in the long run of fifty years or more, the economic role of nuclear power could be more crucial".[1] A comprehensive Canadian study of these questions would, of course, include impacts of special concern to us, notably, considerations of balance of payments and security of fuel supply.

During our debate stage hearings, the Canadian Nuclear Association (CNA) pointed with pride to the fact that: "The CANDU technology is Canadian, the fuel is Canadian and all of the equipment is or can be, produced in Canada."[2] The province or country of manufacture, in fact, is not greatly different for nuclear or coal stations. For nuclear stations it is roughly 72 per cent Ontario, 9 per cent other provinces and 10 per cent U.S. (Figure 8-1). However, 71 per cent of the estimated cumulative lifetime expenditures of a 4 × 850 MW station burning U.S. coal, comprises fuel costs and this represents a $14.4 billion (current dollars) balance of payment drain.[3] Purchases of U.S. coal amounted to $318 million in 1977.[4]

Several participants stressed that a CANDU-nuclear programme was consistent with the federal government's policy of "energy self-reliance". Major objectives of this programme are to reduce reliance on imported petroleum and to alleviate a worsening energy-related balance of payments position through development and use of indigenous energy resources. Others, notably Ontario Hydro, brought the "self-reliance" theme to the

Figure 8.1 Source of Purchases for CANDU Nuclear Generating Stations



SOURCE Based on data from Ontario Hydro.

provincial level, in terms of uranium resources indigenous to Ontario. However, Ontario Hydro is already diversifying its coal supply to draw from western Canadian sources, thereby accepting the consequent penalty of higher fuel costs. Large uranium requirements beyond present contracts would involve out-of-province purchases (probably from Saskatchewan). We endorse Ontario Hydro's attempts to diversify its fuel supply sources not least because of the uncertainty of U.S. coal supplies in the long term. Concomitantly, our reservations relating to the adequacy of Ontario uranium supplies and production capacity to ensure self-reliance for many years using a once-through CANDU fuel cycle, are expressed in Chapter 9.

Provincial and Community-Scale Economic Benefits

A number of briefs to the Commission argued that the high nuclear, coal-supported option with its large "front-end" capital requirements would place such heavy demands on the financial resources of the province that the financing of an adequate effort to develop and deploy renewable options would be pre-empted. By contrast, Dr. Ian A. Forbes, a panelist during the nuclear debate hearings, concluded that the capital requirements to implement Amory Lovins' "soft path" in the U.S. would require an investment of well over 2 per cent of GNP over the period 1975-2000; that it would probably be financially infeasible and, in any case, would exceed the capital requirements of a more conventional energy mix which included nuclear reactors.[5]

The suggestion that Ontario Hydro's financial requirements will "draw capital away" from other social needs is, we believe, oversimplified. Many studies (including the recent federal government document "Financing Canada's Energy Self-Reliance"[6]) have concluded that, as the needs of other sectors (e.g. housing) decline, on account of, for example, demographic changes, capital will become available for the energy sector. This assumes that there is skilful "intermediation" by financial institutions and innovative financing approaches consistent with new large scale energy projects.

However, we consider that capital allocation can and should be influenced by public policies. Many participants, for example, argued that capital would flow to those enterprises promising a good return on investment and having political and regulatory support. This position was endorsed by the CNA, who stated that "anything that makes political and economic sense is financially possible".[7] Not all agree that a large nuclear power programme meets these criteria.

The underlying issues in regard to "economic sense" are first, pricing to reflect the costs of nuclear energy production, and secondly, the economic viability of the system expansion programme. The absence of subsidies is an important condition for appropriate allocation of financial capital through free market competition. Compared with other energy suppliers, Ontario Hydro is subsidized, by the provincial guarantee of its bonds. This allows access to more funds at preferred interest rates. We believe it would be desirable if the balance between electricity and non-nuclear alternative energy developments were to be equalized. This might be addressed through various capital transfer schemes, such as government loans for conservation and renewable technology options at subsidized interest rates.

The relationship between power plant construction projects and provincial and regional economic development is of central significance. In this connection it was suggested by the CNA that the "very large segment of general construction of a CANDU-nuclear plant ... provides a large and steady basis of economic activity in the community".[8] But Ontario Hydro noted that electric power projects are difficult to coordinate with economic cycles; their major local impact, for instance, was decribed as follows:

> The effectiveness of such a stabilization policy is likely to impact regionally and municipally rather than provincially. The direct impact will be confined mainly to the construction sector in the immediate vicinity of the project, while the purchases of machinery and equipment will impact mainly the locations in which production facilities are located. Indirect and induced effects will tend to be somewhat more widely spread but to a lesser extent than a more broadly

> based provincial or national stabilization programme. Also, Ontario Hydro projects tend to be large and few in number, thus reinforcing the locational concentration of economic activity.[9]

Community impact studies undertaken by Ontario Hydro indicate significant impact on municipal services, resulting from the construction of generating stations, particularly in areas remote from urban centres. In recognition of this, Ontario Hydro and the Town of Newcastle have negotiated an agreement whereby the utility will compensate the township to offset the adverse impacts, resulting from construction of the Wesleyville and Darlington generating stations, on various public services. Agreements similar to this are likely to become standard in the future in connection with the building of large generating stations — nuclear or fossil.

Employment

The nuclear power programme has clearly provided substantial direct employment benefits and through the multiplier effects of its expenditures in the economy, a further indirect boost to Canadian employment and income. For example, the Canadian Nuclear Association estimates that the average annual dollar value of work associated with Canada's nuclear industry (public and private sectors together) over the years 1973 to 1976 was $1.2 billion.[10] Further, the Electrical and Electronic Manufacturers Association of Canada (EEMAC) has shown that the currently approved nuclear programme of Ontario Hydro (Bruce A and B, Pickering B and Darlington stations), plus another nuclear plant to be built in the late 1980s will create 88,000 man years of work in the design and construction of the stations and in associated hardware.[11] Based on a study by consultants to the Ontario Ministry of Industry and Tourism,[12] EEMAC has estimated that these five stations would create 2,000 permanent jobs and, through the employment multiplier, 4,000 additional permanent supporting jobs.

In connection with the front-end of the fuel cycle, Ontario Hydro's recently signed contracts with Denison and Preston Mines will create directly 2,600 permanent jobs in the Elliot Lake area.[13]

Although it is obvious that a continuing nuclear power programme will provide employment, critics maintain that nuclear power development is a very expensive means of creating jobs[14] and that it is less effective than similar investment in conservation or renewable energy in providing sustained and broadly dispersed employment opportunites. For example, the development of small scale hydraulic power, lignite and wood, for electric (and/or thermal) power at appropriate locations could have considerable net economic benefits. Especially in eastern and northern regions of the province, the creation of jobs and income through such developments would be particularly helpful. Furthermore, for the most part, the renewable resources involved would facilitate energy self-reliance for both community and province.

In November, 1977, the Commission convened a public seminar "Energy, Jobs and the Economy" with major representation from the Canadian Labour Congress, the Ontario Federation of Labour, government ministries, provincial colleges, public interest groups and Ontario Hydro. Among questions discussed were the transferability of skilled labour between energy technologies, the role of the colleges in training skilled labourers for alternative technologies as well as for the current Ontario Hydro training programme, and the concerns of the labour movement for the health and safety of workers in the energy field. The Congress and Federation officials stressed, in particular, the need for long term energy policy planning by governments; this was regarded as essential to optimize the timing of major energy projects.

The net job creating advantage of energy options is difficult to establish with accuracy. But studies such as the Inhaber review[15] of the inputs into various energy technologies suggest greater material requirements for the renewable options. This implies more job creating potential for these options. However, analysis of energy options should not only consider the number of jobs, but also some of the qualitative impacts such as geographic distribution of job opportunities, stability

of labour demand, skill levels required, working conditions, and organized labour's viewpoints.

A recent study by the U.S. Congressional Office of Technology Assessment[16] addressed this broader range of considerations. While acknowledging the range of uncertainty that exists in this relatively unexamined aspect of energy policy, it concluded that renewable technology employment need not involve major dislocation of a work force, or the establishment of temporary work camps as required, for example, in the construction of a large central generating facility in a remote location. (This pattern, of course, is not unique to nuclear power and would apply to some extent to other conventional energy sources, e.g. oil and gas.) Further, if a major demand developed, for example, for solar energy, it is probable that employment in the area would be as stable as work in any typical building trade. Moreover, the level of skill required would be lower overall than for conventional energy technologies, and the average wage paid per worker might be lower in any labour intensive technology such as solar energy. However, the study noted that if economic growth is not expected to be sufficient to eliminate unemployment, labour intensive industries such as the solar industry would be beneficial to both labour and society by productively employing a larger fraction of the work force.

Implications of Slower Nuclear Growth

Even proponents of nuclear power agree that electricity supply should not be expanded solely to provide jobs. We agree with Ontario Hydro that: "the demand has to be there for the technology."[17] Concern was expressed to the Commission about the impact of further slowdowns in the nuclear power programme on employees of firms in the industry. The CNA quoted AECL estimates that a nuclear moratorium could result in the direct layoff of 17,000 workers "plus many thousands more due to the multiplier effect of such a massive amount of sudden unemployment".[18] However, the CNA estimated that about half of the 31,000 employees in the nuclear industry are in the public sector, federal agencies or provincial utilities, and the remainder are in the private sector.[19] It has therefore been suggested that the impact would be less traumatic because most of the agencies involved have roles other than nuclear related ones. The transferability of employment from and to the nuclear industry is clearly important and merits in-depth study.

Several differing views were offered to the Commission on the desirability of slowing or halting nuclear power development in Ontario. For example, in the Commission's Symposium of September 26, 1977, Sir Brian Flowers rejected a total moratorium but reflected on the wisdom of a "constructive dragging of the feet" on nuclear plant construction. The Canadian Coaliton for Nuclear Responsibility (CCNR), during our hearings, called for a two year moratorium "to allow time for reflection on whether the massive sums lavished on the nuclear industry are necessarily the best use of a very limited resource — investment capital for Canadian industrial development".[20]

However, Atomic Energy of Canada Limited, not unexpectedly, had different perceptions:

> Nuclear energy represents one of the very few technologies with demonstrated capability of contributing to the energy supply in the next century when conventional oil and natural gas are depleted. However, this option will not be available when needed unless the nuclear industry and infrastructure remain in existence. It has required twenty years to develop a commercially viable Canadian nuclear industry whose economic well-being can still not be taken for granted.[21]

We have reviewed two studies which used economic models to analyze the effects of a U.S. nuclear moratorium on consumption, investment and employment levels, electricity costs, the nuclear and coal industries and the physical environment.[22] The Oak Ridge Associated Universities study concluded that a nuclear moratorium would have a "severe" effect on the economic well-being of New England which, because of the high costs of fossil fuels, anticipates a 70 per cent dependence on nuclear power in the future. In the Great Lakes states, which, like Ontario, have access to both Appalachian and western coals, a nuclear moratorium would increase electricity costs but at no more than the average for the U.S. as a whole. The

study further concluded that 50,000 nuclear related jobs would be eliminated. The study considered the most important impact to be the need for 1 to 3 billion additional tons of coal by 2000, thereby probably doubling the number of coal mining deaths that would otherwise occur. Greatly increased CO_2 from coal-fired plant emmissions was regarded as the most serious environmental problem.[23]

Both studies concluded that, although nuclear power appears likely to be cheaper than any feasible alternative (except for some Western states with access to low sulphur strip-mined coal), as long as some combination of a coal, oil or conservation response to the nuclear moratorium were put in place quickly, overall U.S. GNP would decrease by not more than 1 per cent annually by 1985. On the other hand, the costs of not preparing alternative supply/conservation programmes would be very large, e.g., up to 30 per cent of GNP in the event of an uncompensated 100 per cent shortfall in the expected nuclear capacity.[24]

Because the information base is far from adequate, at present we can only draw very general conclusions. We believe, in particular, that in the event of a deliberate major nuclear slowdown, Ontario Hydro customers would face somewhat higher electricity bills and the Gross Provincial Product would suffer. This would not be catastrophic as long as appropriate alternative power supplies and conservation technologies and practices were developed in time. Reactor manufacturers and component suppliers would, of course, suffer the most direct effect.

The Status of the Nuclear Industry

The proponents of nuclear power have argued that nuclear energy represents one of the very few technologies with a demonstrated capability to contribute significantly to our energy supply in the decades ahead, thereby providing an otherwise elusive potential for substantial energy self-reliance based on Canadian technology, expertise and resources. They conclude that the role of nuclear energy should therefore be significantly and quickly expanded, most importantly to replace the use of liquid fuels which not only will continue to escalate in price as existing reserves are depleted over the next few decades but which furthermore ought increasingly to be reserved for important alternative uses (chemical feedstocks, for example). Events subsequent to the 1973 OPEC oil embargo added a new urgency to this argument, bolstering further the already high expectations within the Canadian nuclear industry for the growth of nuclear power. As recently as the summer of 1977, the CNA presented an optimistic view of the future path of the nuclear power programme:

> Today the Canadian nuclear industry employs over 31,000 people,[25] nearly three-quarters of them in Ontario. By the end of the century employment could more than quadruple to over 130,000 jobs. These jobs provide challenging employment opportunities for a wide range of qualified and skilled individuals. Steady growth of nuclear power, as indicated by current plans, will ensure the continuing productive use of those now employed and those being trained, and will avoid dispersing these qualified people to other industries or other countries. At the present time, manpower and other resources are fairly closely matched to the work which needs to be done. To date, the private sector has built up an excellent competence in Canada in a high technology industry and this achievement in human resources should be preserved and expanded in line with the needs for additional nuclear power.[26]

Other evidence and analysis before this Commission, however, has suggested that the future economic health of the Canadian nuclear industry — and therefore the future availability and strength of the nuclear option in Ontario — cannot be taken for granted.

During testimony and cross-examination before this Commission in December 1977, the Canadian Nuclear Association (CNA) registered "deep concern" with respect to the health of the industry over the next ten years.[27] Both Atomic Energy of Canada Limited (AECL) and the CNA noted that the structure of the likely Canadian domestic demand for nuclear power over the remainder of the century — then projected to be 82,000 MW installed by 2000, of which 47,000 MW would be in Ontario — is now insufficient to keep industry work loads at satisfactory levels, particularly over the critical next decade. Earlier, more optimistic projections for the growth of nuclear

power in Canada have not materialized, we were told, partly because the compulsion to turn to nuclear energy has been deferred by provinces blessed with adequate supplies of conventional sources of energy. The domestic market for nuclear power therefore is, and will continue to be, dominated by Ontario Hydro. The CNA, however, stated that even Ontario Hydro's proposed large nuclear programme would not by itself generate sufficient business to keep the nuclear industry healthy.

Under these circumstance, the CNA informed us that the Canadian nuclear manufacturing industry is currently operating at about 50 per cent of its capacity and that even lower capacity utilization will be experienced over the next two to three years. Given the present projections for Canadian domestic nuclear requirements, both the CNA and AECL emphasized that unless a successful CANDU export programme can be mounted for at least the next ten years, some companies will be forced to withdraw from the industry and technical personnel will be dispersed over the next three to four years.

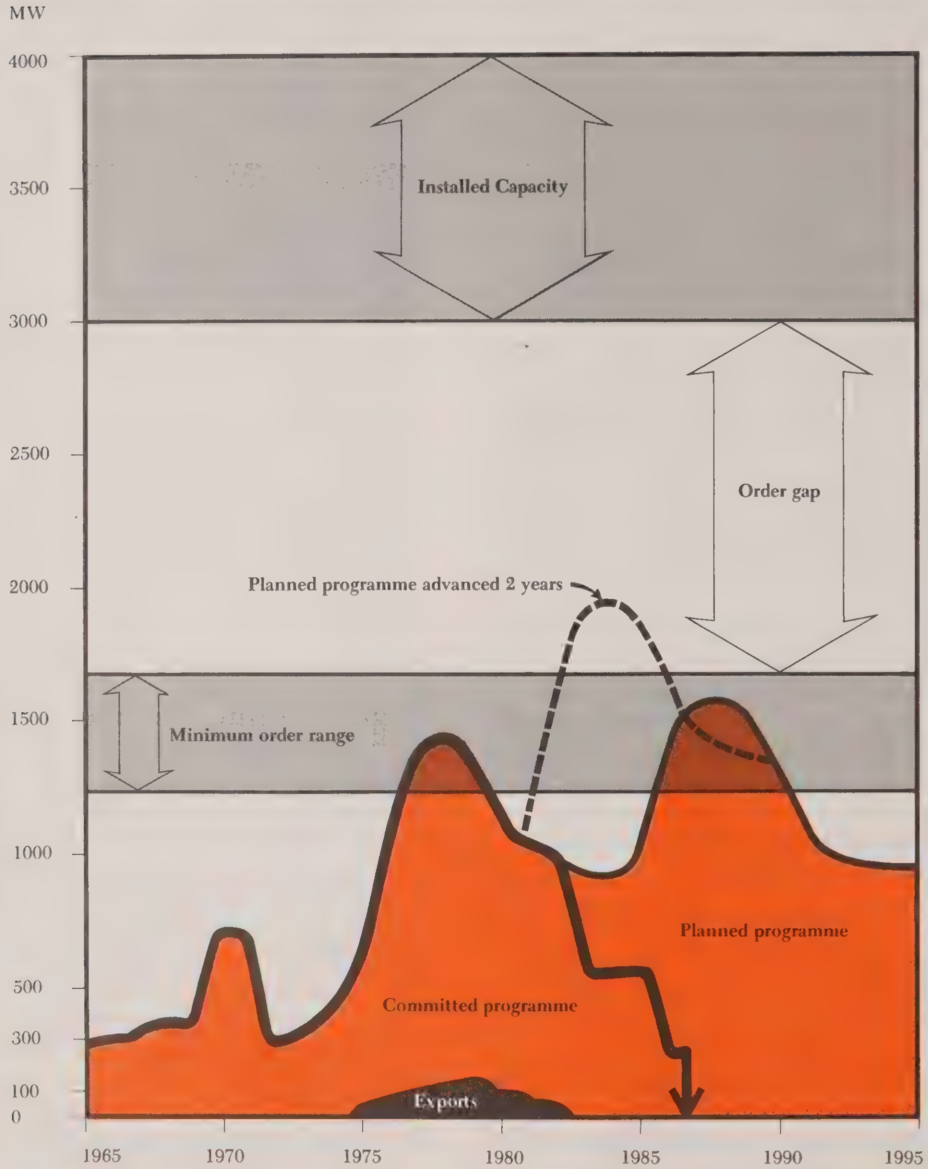
These assessments of the problems faced by the nuclear manufacturing industry were based on the assumption that installed nuclear capacity in Canada would reach about 82,000 MW by 2000, of which some 47,000 MW would be located in Ontario. A more recent projection, however, made available to us by AECL during June 1978, forecasts only 60,000 MW installed nuclear capacity in Canada by the year 2000, of which about 31,000 MW would be located in Ontario. Although the forecasters note that an upturn in the nation's economy might lead to some increase in this projection, they also acknowledge continuing uncertainty and vulnerability to further reductions, particularly in Quebec's nuclear programme, which accounts for 20,000 MW of the 60,000 MW now forecast for Canada by 2000. The current forecast compares with a 1974 Canadian projection of 131,000 MW installed nuclear capacity for the year 2000.

Concern over the future of the nuclear industry in Canada led the CNA to commission a private consulting firm in early 1978 to carry out a detailed assessment of the present state and prospects of the industry. Although a final version of this report — entitled *The Economic Impact of the Canadian Nuclear Industry* — is not available at present (July, 1978), the initial findings of the study were presented at the CNA annual conference in June, 1978. The study's findings and conclusions confirm, document and amplify the concerns expressed by the CNA to the Commission late in 1977 with respect to the uncertainty, lack of continuity and low order levels associated with the CANDU programme.

Figure 8-2 and the following key points summarize the study's findings.

- As a result of the optimistic demand forecasts of the early 1970s for CANDU units in Canada and abroad, some 60 major firms now employing 6000 people installed a manufacturing capacity capable of supplying nuclear equipment for an average of 3000 to 4000 MW of CANDU plants per year.
- Based on the currently confirmed or assured domestic and export programmes, CANDU manufacturing activity or "manufacturing plant loading" will reach its peak during 1978 and will decline continuously thereafter. The 600 MW Gentilly 3 station in the province of Quebec has not been included because although it is committed, it has not been firmly scheduled. Its addition would not, however, materially affect the downturn.
- The minimum order level which the nuclear manufacturing industry considers necessary if existing equipment suppliers are to remain in business — namely, components for an average of 1200 to 1700 MW of CANDU plant per year — will barely be achieved even during the 1978 peak year. Plant utilization across the industry currently averages 53 per cent and can only decline further based on the confirmed nuclear programme. The situation is so critical that some manufacturers are already considering leaving the industry.
- Planned but not yet committed additions to Canada's existing nuclear power programme to the year 2000 are considered to be limited to Ontario and Quebec. Installed nuclear capacity for Canada in 2000 is projected to be 33,000 MW, of which 31,000 MW would be in Ontario and most of the remainder in Quebec. This planned power programme will, if implemented, result in a continuation of manufacturing orders, but it will not generate increased work levels for the industry. The

Figure 8.2 Nuclear Manufacturing Plant Loading, 1965-1995



SOURCE "The Economic Impact of the Canadian Nuclear Industry," initial findings presented by Leonard and Partners Limited to the Canadian Nuclear Association Annual Conference, Ottawa, June 1978.

health of the industry as currently structured will therefore remain critical. The effect of bringing the planned programme forward by two years improves the situation temporarily, but manufacturing activity would still remain well below capacity and only slightly above the 1978-79 peak.

- The nuclear design and engineering sector can be considered a vanguard to the manufacturing sector, providing an early indication of future prospects since downturns or upturns are experienced first by the design and engineering sector. If no further orders beyond the currently confirmed programme are available over the next two to three years, then the private nuclear engineering and consulting sector will be operating at 15 per cent of its 1977 staffing level by 1980. The public nuclear design and engineering sector will be similarly affected, but more slowly. Once dispersed, this expertise is not readily re-established.

The study concludes by emphasizing that if the nuclear industry is to survive, coordinated and immediate action is necessary to generate continuity and sustained orders. Confirmation of the planned "post-Darlington" domestic programme is urged. To fill the remaining large (1500 MW per year) order gap, three basic options are proposed, presumably to be pursued simultaneously.

First, the study proposes that the domestic nuclear power programme in provinces other than Ontario be accelerated or expanded. The potential offered by this option, however, must in our view be considered limited, particularly in light of the most recent Canadian forecast which again revised downward the expected installed nuclear capacity by the year 2000 to 60,000 MW. Other than the projection for Quebec, which was seen as vulnerable to further reduction, sizable new or expanded programmes in other provinces seem unlikely.

The second alternative put forward by the study proposes that further exports of CANDU stations be attempted. Recent history, however, inspires confidence neither in the ease with which Canada is likely to achieve further exports beyond the two reactors sold to Argentina and South Korea, nor in the commercial profitability of such ventures. (However, it is encouraging to note the recent (July 1978) progress reportedly being made in connection with major potential CANDU sales to Rumania.) To be sure, the international reactor market, overwhelmingly dominated by the light water reactor, is a highly competitive business to which CANDU is not only a late-comer but somewhat of an aberration. Having a good product, probably even the best product, appears not to be sufficient.

Furthermore, evidence before the Commission confirms that the most likely and, from the manufacturing industry's point of view, the most beneficial, export market for CANDU is in Less Developed Countries (LDC). The acceptability and potential of the LDC market may, however, be limited in some instances by political considerations or concern over the application of Canada's stringent safeguards. For these reasons, exports to industrialized nations may be preferable if they can be achieved. Such potential buyers, however, may well already be using the more established light water reactor and, unlike the LDCs, will almost certainly possess and wish to employ their own engineering and manufacturing capability. Hence, CANDU units exported to industrialized nations are likely to take the form of licensing arrangements whereby the licensee would, for a fee, be allowed to use the CANDU design to produce and use CANDU reactors and ultimately market them abroad. Such an arrangement is currently under consideration by an Italian firm and the government of Rumania and if successful would help to get more CANDU units operating outside Canada.

We have been told, however, that the private Canadian nuclear manufacturing industry is concerned that this approach to marketing CANDU could result in minimal Canadian content beyond the first unit built and that the effect on the long term viability of the Canadian nuclear industry therefore could indeed be counter-productive, not least because the licensing approach will create foreign producers of CANDU reactors with which Canadian manufacturers will have to compete in the future.

A further approach to making CANDU exports more attractive, proposed by AECL and reportedly part of the discussions with Japan, would be to offer guaranteed or preferential access to Canadian uranium to a purchaser of CANDU units. Such an

approach would appear to be an imaginative marketing strategy. Depending on the nature of the arrangement and the quantities involved, however, this strategy could have important and possibly adverse ramifications on both the uranium production capacity available for future Canadian use and the relationships with our existing uranium customers.

A third option offered by the study's authors to fill the order gap suggests the construction of CANDU stations in Canada committed to export electricity to possible markets in the United States. We are, of course, familiar with this concept. A preliminary study for the Ministry of Industry and Tourism presented to the Commission suggested further exploration of the possibility of a CANDU plant constructed and managed by Ontario Hydro and owned by an approved consortium, dedicated to the export of electricity to the United States.

Because of the significance, from many points of view (socioeconomic, political and environmental), of this proposal, we present briefly below the arguments for and against it. We have concluded that the proposal should not be dismissed out of hand and deserves further in-depth study.

The Case for the Proposal

- at present, many tonnes of uranium are being exported by Ontario. If a portion of these exports were diverted for the production of electricity in Ontario, the environmental impact of the mill tailings (which we regard as a most serious waste disposal problem) would be unchanged, but a high value-added export commodity (electricity) would replace a low value-added mineral with favourable balance of payments results;
- the design and construction of the station would create a large number of jobs for professional, technical and skilled workers in the province, and enhance the health of the Canadian nuclear industry;
- the firm export of electricity to the United States (especially during a possibly critical period of energy shortages, during the 1990s and beyond) would enhance Canada's international standing;
- the export of CANDU reactors and technology might be facilated since some nations might be encouraged to consider using the CANDU system;
- the agreement could state that the plant would become the property of Ontario Hydro after a certain period so that there would be no permanent alienation of a valuable waterfront site;

The Case against the Proposal

- until the problems of radioactive waste disposal are solved, beyond reasonable doubt, it would be very undesirable to build a nuclear power station dedicated for export of electricity to the United States. The radioactive wastes would be deposited in Ontario, the high quality energy would be exported;
- as long as there remains even a small risk of a major nuclear power station accident (which there will always be) Ontarians should not be exposed to additional risk while another country reaps the benefits;
- after thirty to forty years' operation a nuclear reactor requires decommissioning; this may not only be a hazardous procedure but will involve disposing of a considerable amount of radioactive material;
- a site will have to be acquired, thus reducing the options available to Ontario Hydro;
- the building of a CANDU power station would require a large capital outlay, which would have to be borrowed.
- if there are major technological breakthroughs, especially in breeder reactors, nuclear fusion, or solar electric energy, electric power generated by CANDU reactors may be non-competitive by the early years of the next century;
- it is not clear, based on evidence to date that there will in fact be a sizable and long term market in the U.S. for electricity generated by CANDU units in Canada.

In the event that the pursuit of any or all of the above mentioned options does not provide timely, sufficient and sustained relief to the nuclear manufacturing industry, the immediate and precise impact on Ontario Hydro's proposed nuclear programme is difficult to predict. Some manufacturers would be forced to leave the industry as rationalization took place and unused capacity is removed. Single or monopoly suppliers may remain to provide components to Ontario Hydro, replacing the generally two-supplier industry which now exists.

Costs to Ontario Hydro might rise by an estimated 10 per cent if a protected rather than a competitive industry were to emerge. However, it is not clear whether the remaining single suppliers would have sufficient capacity to meet Ontario Hydro's needs, or whether the committed nuclear business offered by Ontario Hydro would be characterized by the appropriate timing, continuity, size and stability to sustain a full range of component manufacturers for an indefinite period. The possibility that some CANDU station components might have to be imported from foreign suppliers can therefore not be ruled out.

Clearly, even if it is assumed that the 31,000 MW of CANDU plant now forecast to be installed in Ontario by 2000 will in fact be needed and built, the strength and very availability of the nuclear option to Ontario in the 1980s and beyond is critically dependent upon the success of the three options outlined above. However, neither the content nor the outcome of at least the first two of these strategies — expanding the domestic nuclear programme outside Ontario or attempting further CANDU exports — is likely to be amenable to significant influence or control by the Province of Ontario. Furthermore, the potential represented by the three options is unclear and may be insufficient to fill the 1500 MW annual order gap required to provide a stable environment for the manufacturing industry. It is therefore difficult to avoid the conclusion that the nuclear option, far from guaranteeing energy self-reliance for Ontario, at best promises uncertainty.

Chapter Nine

Uranium Resources

ONTARIO Hydro's current commitment to nuclear power, a total of twenty reactors at Pickering A and B, Bruce A and B and Darlington, represents an investment by the people of Ontario in excess of $14 billion. Furthermore, Ontario Hydro has proposed that future additions to its base load generating capacity be made at a ratio of two-thirds nuclear to one-third coal. Depending on the forecast for future electrical energy demand, such an ambitious strategy could, if approved and implemented, make Ontario one of the most nuclear-dependent jurisdictions in the world by early next century. The viability of such an approach to planning Ontario's future electrical system is fundamentally contingent upon the availability of very large, long-term and secure supplies of uranium to Ontario Hydro to fuel what would be a massive capital investment in nuclear power.

A principal and recurring argument heard by this Commission has suggested that CANDU technology represents a uniquely attractive energy option since it is based on the use of natural uranium with which Canada and Ontario are well endowed. For Ontario, this argument seems even more compelling since uranium, we have been told by nuclear proponents, is the "only" significant and unexploited energy resource indigenous to the province which offers the potential for a degree of energy self-reliance.

In our view, this argument forms what is perhaps the most central and strategic rationale in the case for an expanding and large commitment to nuclear energy in Ontario in the decades ahead. As other parts of this report indicate, we have concluded that although uranium is an extremely important resource, it is not the only remaining, unexploited energy resource indigenous to Ontario. Furthermore, there is almost universal agreement that if nuclear power is to play a major role in supplying the province's energy needs in the longer term, that is to say well into the next century, then we will have to develop, and hence accept the inevitably higher risks as well as the benefits of, more advanced fuel cycles based on the recycling of plutonium or the "breeding" of fissile U-233 from fertile thorium.

More importantly, however, we have concluded that the future availability of Ontario or Canadian uranium to Ontario Hydro, in the quantities and at the prices and times it may be desired for a large nuclear programme in the 1990s and beyond, may be subject to an unpredictable and highly complex set of parameters likely to be amenable to only minor control by the Government of Ontario. As the recent report of the Ontario Select Committee on Ontario Hydro Affairs examining Ontario Hydro's $7 billion uranium contract for its existing nuclear commitment stressed, the existence of large uranium reserves in the ground in Ontario does not guarantee that this resource will be produced at a price acceptable to Ontario Hydro. If uranium increasingly becomes a global, strategic resource replacing dwindling and uncertain supplies of petroleum, then the complexity and difficulty of future uranium contract negotiations should not be underestimated. Potential supplies and production capabilites, government policies on uranium exports and the nature of the international market in uranium will all be important factors in the future of nuclear power.

Figure 9.1 Uranium-Bearing Areas in Canada Assessed in 1976

SOURCE Energy, Mines, and Resources Canada.

The Canadian and Ontario Uranium Resource Potential

The OPEC oil embargo in 1973 caused a dramatic turnaround from what had been a buyer's to a seller's market in uranium as customers moved to acquire long term uranium supplies for nuclear generators to reduce their dependence on OPEC oil. In response to these circumstances, the international spot price for uranium has escalated from under $10 a kilogram in early 1973 to the $130 a kilogram level in early 1978, a formidable increase even compared with the four-fold increase in the price of oil over the same period. One effect of this price increase has been a rapid rise in exploration expenditures in Canada over the past four years to an estimated $72 million during 1977. This effort is currently being surpassed only in the United States, where over $250 million was spent on uranium exploration in 1977.

As part of the federal government's support for a development programme, Canada established the Uranium Resource Appraisal Group in September 1974 to provide a data base for government and industry and to audit annually Canada's uranium resources. This group's third annual assessment, completed in early 1977, suggests that Canada is well endowed with uranium and possesses geological formations favourable to the identification of additional resources (Figure 9-1 and Table 9-1). The quartz pebble conglomerate in the Elliot Lake and Agnew Lake regions of Ontario contain over 60 per cent of Canada's presently known and economic uranium resources. Over 60 per cent of Canada's estimated additional resources are also in Ontario.

While this analysis suggests that Canada and, in particular, Ontario are in an enviable position with respect to the uranium resource base, a number of additional factors must be understood and weighed if a prudent and realistic assessment of future supplies is to be made:

• four categories associated with varying levels of confidence are used to estimate Canadian uranium resources. The "measured" category can be considered to be proven with a 100 per cent confidence level and the "indicated" category is generally considered to be accurate to within plus or minus 20 per cent of the estimate, yielding an 80 per cent confidence level. The sum of these two classifications is designated "reasonably assured". The third category, "inferred", is considered by the Uranium Resource Appraisal Group to have a 70 per cent confidence level. However, Dr. David Robertson, a consulting geologist to Ontario Hydro, informed the Commission that reserves designated as "inferred" have such a low level of confidence associated with them that organizations such as the Ontario Securities Commission and the Securities and Exchange Commission in the United States will not permit their inclusion in a prospectus. Dr. Robertson stated that the level of confidence in the resources in the final category, "prognosticated", must be considered to be zero, and that the numbers bear no relationship to any factual measurements.

• As Table 9-2 indicates, only a small percentage of Canada's and Ontario's total uranium resources are in the first two high confidence categories. Ontario's reasonably assured uranium resources total approximately 125,000 tonnes at prices up to $156 per kilogram, about 1.5 times the international spot price for uranium in early 1977 when these figures were calculated. Ontario has existing export commitments of approximately 62,000 tonnes. In addition, Ontario Hydro recently received approval to purchase about 76,000 tonnes of uranium from Preston and Denison Mines over the next forty years to fuel all its currently committed stations for thirty years at 80 per cent capacity.[1] These commitments total approximately 138,000 tonnes and will therefore "deplete" the current "reasonably assured" supplies.

• The large proportion of Canadian and Ontario uranium resources in the low confidence level "inferred" and "prognosticated" categories makes it clear that exploration will be critical if some proportion of these large, additional estimated quantities of uranium is to be brought into the two "reasonably assured" categories and produced. Exploration is however, an extremely risky business requiring increasingly large amounts of capital which may not be entirely available in Canada. Indeed, most of the recent large expenditures on uranium exploration in Canada over the past four years (over half this activity was in Saskatchewan in 1977) have come from foreign sources. Although

Table 9.1 Major Recoverable[1] World Uranium Resources[2], 1977

Source	Reasonably Assured (Thousands of Tonnes)		Estimated Addition (Thousands of Tonnes)		Total
Australia	296		49		345
Niger	160		53		213
South Africa	348		72		420
United States	643		1,053		1,696
	Measured	Indicated	Inferred	Prognosticated	
Canada	83	99	307	349	838
Ontario	49	76	246	182	553
Saskatchewan	31	21	58	119	229

Decreasing confidence in estimates →

Table 9.2 Uranium Resources Recoverable[1], by Category, 1977

	Reasonably Assured		Estimated Additional		Total
	Measured	Indicated	Inferred	Prognosticated	
	100% confidence	80% confidence	70% confidence	0% confidence	
Canada (per cent of total resources)	10	12	37	41	100
Ontario (per cent of total resources)	9	14	44	33	100

1 At up to $156 per kilogram, about 1.5 times the international spot price when these figures were calculated.

2 Comparative figures are approximate because of the variations in the resource classification systems used by different nations and international organizations. The most recent Uranium Appraisal Group report, published in July 1978, was not available when this data was prepared, but it would change the Canadian figures only marginally.

SOURCE Based on data from Energy, Mines and Resources, Canada and the Organization for Economic Co-operation and Development.

1 At up to $156 per kilogram

SOURCE Based on data from Energy, Mines, and Resources, Canada.

there are no federal government restrictions unique to uranium exploration, once a project has reached the production stage, foreign equity participation must be limited to one-third of the total assets involved in the project. This federal government policy could inhibit uranium exploration for several reasons. First, large foreign enterprises, not unlike their domestic counterparts, do not like to commit risk capital out of proportion to their ownership. Secondly, Canadian partners in the uranium field, we have been told, are not always easy to find. Finally, even if these obstacles have been overcome, a foreign investor is faced with uncertainty as to whether the uranium found and produced can be exported. This dilemma was well demonstrated by a recent year-long embargo on shipments of Canadian uranium to Japan and to some members of the European Economic Community imposed as a result of Canada's tough new safeguards on the export of nuclear materials. Federal policies will clearly be an important determinant in the development of uranium resources.

- Dr. David Robertson, in his appearance on an Ontario Hydro panel before the Commission, expressed firm optimism that additional quantities of uranium could be identified and found as higher prices for uranium stimulate increased exploration. However, he also cautioned that the relationship between price increases and the availability of additional uranium supplies is highly uncertain. For example, despite growing exploration expenditures in Canada over the past four years as a result of a ten-fold increase in international spot prices, the total potential Canadian uranium resource base in all four categories grew only about 21 per cent during the period.

Canadian Uranium Policy

The degree to which and the rate at which nuclear power could be expanded in Ontario in the decades ahead is, in the first instance, clearly a function of the confidence levels associated with the potential uranium resource base. However, to make realistic judgements about these questions the Canadian and Ontario situations must be viewed and assessed in an international context. Most of the nations that appear committed to very large nuclear power programmes — West Germany, Japan and France, to name a few — do not have indigenous uranium resources. Canada, on the other hand, possesses approximately 20 per cent of the western world's currently estimated total uranium resource potential. Indeed, as Table 9-1 illustrates, Ontario has a total uranium potential currently exceeded by only one jurisdiction in the world, that of the United States. It is, in our view, unlikely and perhaps even undesirable, that a Canada so potentially well endowed with energy resources could insulate itself from the future strategic energy requirements of our important trading, political and military partners whose energy problems appear to be far more serious than our own and whose general economic well-being is of vital importance to us. Certainly, an unenlightened Canadian posture on these matters could imply serious economic and political risks for Canada. Therefore, the projected growth in world nuclear power and the concomitant uranium requirements are of considerable consequence to decisions about the future role of nuclear energy in Canada and in Ontario.

In a recently published joint report on uranium, the OECD Nuclear Energy Agency and the International Atomic Energy Agency have revised downwards their forecast for world nuclear power growth. This latest revision, due to a variety of factors, forecasts a world nuclear generation capacity between 1000 and 1890 GW by 2000, replacing an earlier estimate of 2005 to 2480 GW. The lower limit of this new forecast is considered to be the most likely pattern because it is based on present trends in energy utilization. These downward revisions reduce the anticipated demand for the world's uranium resources and will tend to increase the adequacy of existing uranium reserves. The report goes on, however, to caution that the lower demand estimates for uranium are, in part, offset by the general recognition that commercial recycling of spent fuel will now probably not take place before the 1990s. Under these conditions, the world's current, reasonably assured uranium reserves will be committed under the higher nuclear growth forecast by 1986 and for the lower projection by 1988 to cover the lifetime requirements of reactors in being at that time. Even if spent fuel were reprocessed and recycled as early as possible

Table 9.3 Uranium Commitments, Canada and Ontario

	Canada (Thousands of tonnes)		Ontario (Thousands of tonnes)	
Projected Nuclear Capacity by 2000	82,000 MW	60,000 MW	47,000 MW	31,000 MW
Cumulative Consumption to 2000	95.0	80.0	70	56
30-year Consumption to 2030	345.0	254.0	200	131
Existing Export Commitments	73.4	73.4	62	62
Total Committed	513.4	407.4	332	249

Table 9.4 Uranium Resources Recoverable[1], Canada and Ontario

Category	Canada (Thousands of tonnes)	Ontario (Thousands of tonnes)
Measured	83	49
Indicated	99	76
Inferred	307	246
Total	489	371
Adjusted Reserve[2]	377	282

SOURCE (Table 9.3) Estimates by Royal Commission on Electric Power Planning

1 At up to $156 per kilogram.

2 The sum of tonages in the measured, indicated and inferred categories weighted with factors of 1.0, 0.8 and 0.7 respectively to reflect reliability.

SOURCE (Table 9.4) Based on data from Energy, Mines, and Resources, Canada.

— generally thought to be about 1985 — these reserves would be committed only two to three years later. Thus, on an international basis, presently known and reasonably assured uranium reserves will be insufficient to meet the demand by 1990. The authors therefore conclude that the world uranium industry faces a "formidable challenge" and that existing reactor systems "must in time be replaced by more advanced reactor systems that will conserve uranium resources if nuclear power is to play a major role in supplying world energy needs in the longer term".[2]

In view of Canada's uranium position in relation to the international situation, the Canadian federal government, which has jurisdiction over uranium, in September 1974 announced a new uranium policy designed to allow and encourage the Canadian uranium industry to continue to participate fully in the rapidly growing and highly lucrative world market while attempting to ensure that Canadian domestic requirements could be fulfilled. To achieve this objective, the policy requires that: sufficient uranium be reserved for domestic use to enable each nuclear reactor operating, committed, or planned ten years into the future to be fuelled at an average annual capacity factor of 80 per cent for thirty years; export contracts be limited to a maximum duration of ten years, with contingent approval for an additional five years; and utilities maintain a contracted fifteen year forward supply for all operating and committed reactors.

Under this policy each Canadian uranium producer is required to maintain a certain level of reserves for domestic use. In assigning the domestic allocation amongst Canadian uranium producers, resources in the three categories — measured, indicated and inferred — are included but with weighting factors of 1.0, 0.8 and 0.7 respectively to reflect the varying reliabilities associated with each category. The sum of the weighted tonnages is termed the "adjusted reserve". Currently, to meet the thirty year fuel requirements of the 16,240 MW now operating or committed in Canada in the ten year forward period to 1988, the protected "allocated domestic reserves" which Canadian producers must collectively set aside total approximately 70,000 tonnes or about 21.5 per cent of the "adjusted reserve".

Although the federal uranium policy appears to guarantee that adequate supplies of uranium will be available to meet the needs of domestic utilities, the policy has, in our view, serious limitations from the Ontario point of view which are discussed below. In addition, if current official projections for the growth of nuclear power in Canada to the year 2000 are compared with existing estimates of our seemingly large potential uranium resource base, it appears that the Canadian domestic situation with respect to the supply and demand for uranium will not be significantly different from the world context described earlier. Until recently, official projections of the most probable nuclear power growth rates in Canada forecasted a total installed capacity of approximately 82,000 MW in Canada by 2000. It is generally assumed that slightly more than half of this capacity — about 47,000 MW according to Ontario Hydro's Long Range Forecast 48A (LRF 48A) — would be in Ontario. While this report was in preparation we received revised forecasts which now project installed nuclear capacities of 60,000 and 31,000 MW in Canada and Ontario respectively by 2000. Tables 9-3 and 9-4 summarize the impact of these projections on the uranium resource base if it is assumed that no recycling of spent fuel takes place before 2000 and no further uranium exports beyond existing commitments are undertaken. Even when the resources in all of the three categories are used but weighted for reliability, the nuclear capacity projected to be in place in Canada by 2000 in both the 82,000 and the 60,000 MW forecasts could not be fuelled for its assumed thirty year lifetime to 2030. Certainly, no additional nuclear capacity could be added after 2000 without heavy reliance on resources currently in the prognosticated category, which must be considered to have a zero level of reliability until exploration can bring some of these resources into a higher confidence level category.

Tables 9-3 and 9-4 suggest that the situation for Ontario is slightly but not significantly more favourable. If Ontario were to rely on uranium resources indigenous to the province, the resources in the three categories, weighted to reflect reliability, would be insufficient to fuel 47,000 MW of nuclear capacity (LRF 48A) in Ontario by 2000 for

Table 9.5 Major World Attainable Uranium Production Capacities 1976-1990

	1976		1985		1990	
Country	Thousands of tonnes	Per cent of western world total	Thousands of tonnes	Per cent of western world total	Thousands of tonnes	Per cent of western world total
Australia	.36	2	11.80	13	20.00	18
Niger	1.46	7	9.00	10	9.00	8
South Africa	3.40	15	12.50	14	12.00	11
United States	9.80	44	36.00	39	47.00	43
Canada	4.85	22	12.50	14	11.25	10

SOURCE Based on data from the Organization for Economic Co-operation and Development and Energy, Mines, and Resources, Canada.

its thirty year lifetime. If it is assumed that only 31,000 MW of nuclear capacity is installed by 2000, these reactors could be fuelled for thirty years with a slight margin. However, even if nuclear units are deployed at a much less ambitious rate than planned over the next two decades, it should be recognized that the recently approved Ontario Hydro uranium contracts plus existing export commitments would already more than exhaust Ontario's currently estimated reasonably assured resources in the measured and indicated categories. The contracts could provide thirty year lifetime fuel for Ontario's approved nuclear stations to Darlington plus an additional 4000 MW, for a total of approximately 18,000 MW.

Uranium Production Capability

Judgements with respect to the uranium resource potential in the ground are both important and problematic. However, in evaluating the status of the uranium resource base, it is absolutely critical to consider whether all of this potential resource can in fact be made physically available at a rate corresponding to the increasing demand. The uranium production capability — the capacity to mine ore and to process it in a mill into a form (U_3O_8) ready for refining and fabricating into fuel — is therefore of paramount importance to the viability of existing and possible future nuclear power programmes.

On a world basis, projected production capabilities could support the expected growth of nuclear power until about 1990 in all instances except under conditions of accelerated nuclear power growth rates without recycling.[3] However, even then, economic and political conditions must be favourable if these production capabilities are in fact to be attained. Beyond 1990, there will be increasingly large demands on annual world production output and no assurance can be given that supply will be able to keep pace with projected demand. Thus there is an urgent need to increase exploration activity in order to bring low confidence level resources into the reasonably assured category and to add new discoveries to the resource base.[1]

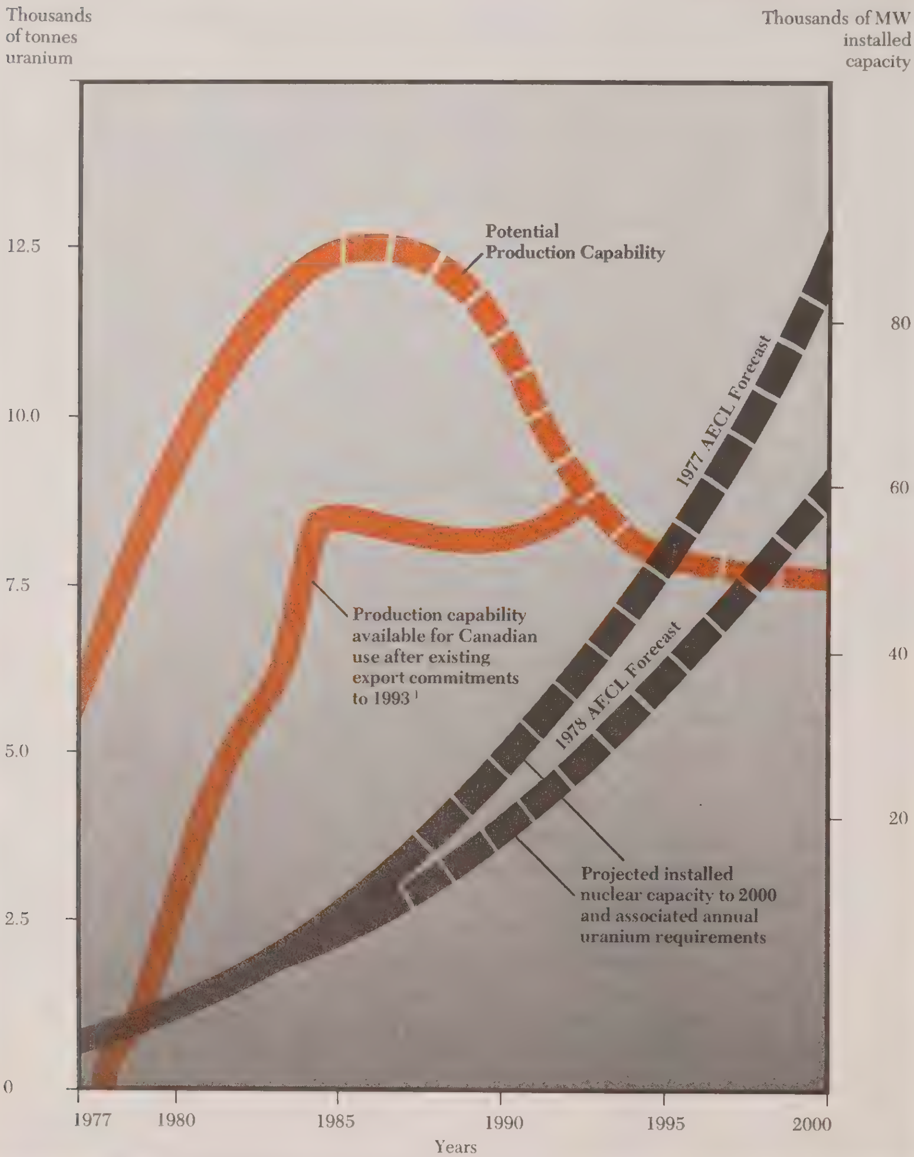
Canada is and will continue to be a major force in these world markets (Table 9-5). Canadian uranium production totalled approximately 5800 tonnes in 1977, about 21 per cent of world uranium production. During 1977 an estimated 9 per cent of Canada's output was required domestically, the remaining 91 per cent going to meet Canada's export commitments to Japan, the United Kingdom, the United States, Germany, Finland, Switzerland, Spain and Korea, which total 73,400 tonnes to 1993. Indeed, during 1976 and 1977, export commitments exceeded production capacity. Shortfalls were met by drawing on the federal stockpile and producer inventories.

Current expansion and development plans in Ontario and Saskatchewan, which will cost an estimated $500 million over the next five years, will boost Canada's annual uranium production capacity to about 8000 tonnes by 1980. Additional currently known resources could raise the Canadian production capacity to a maximum attainable level of about 12,500 tonnes per annum by 1984 or 1985. This level of output could be maintained for perhaps two or three years before physical constraints will cause output to decline due to depletion of certain deposits and the mining of lower grade ores.

It is, however, important to recognize that these projections of attainable production capacity are subject to a number of possible constraints which may seriously affect the extent to which these potential capacities will in fact be achieved by 1985:

- Shortages of specialized equipment and skilled labour have been experienced in the past in Canada's mining industry and may prove to be an important limitation in the future. While new equipment may be required, skilled mining personnel may be very difficult to find. Indeed, while on a recent tour of the mining and milling complex at Elliot Lake, we were told that the mining companies were already having great difficulty attracting miners to staff uranium production expansion programmes despite high unemployment amongst miners in nearby Sudbury. Most mining operations are located in increasingly more remote regions of Canada, making it difficult to attract employees who, like many Canadians, prefer the comfortable living standards available in major centres. Mining

Figure 9.2 Annual Potential Canadian Uranium Production Capability and Requirements



1 Approximate, as annual delivery schedules are subject to adjustment.

SOURCE Based on data from Organization for Economic Co-operation and Development; Energy, Mines, and Resources Canada; and Ontario Hydro.

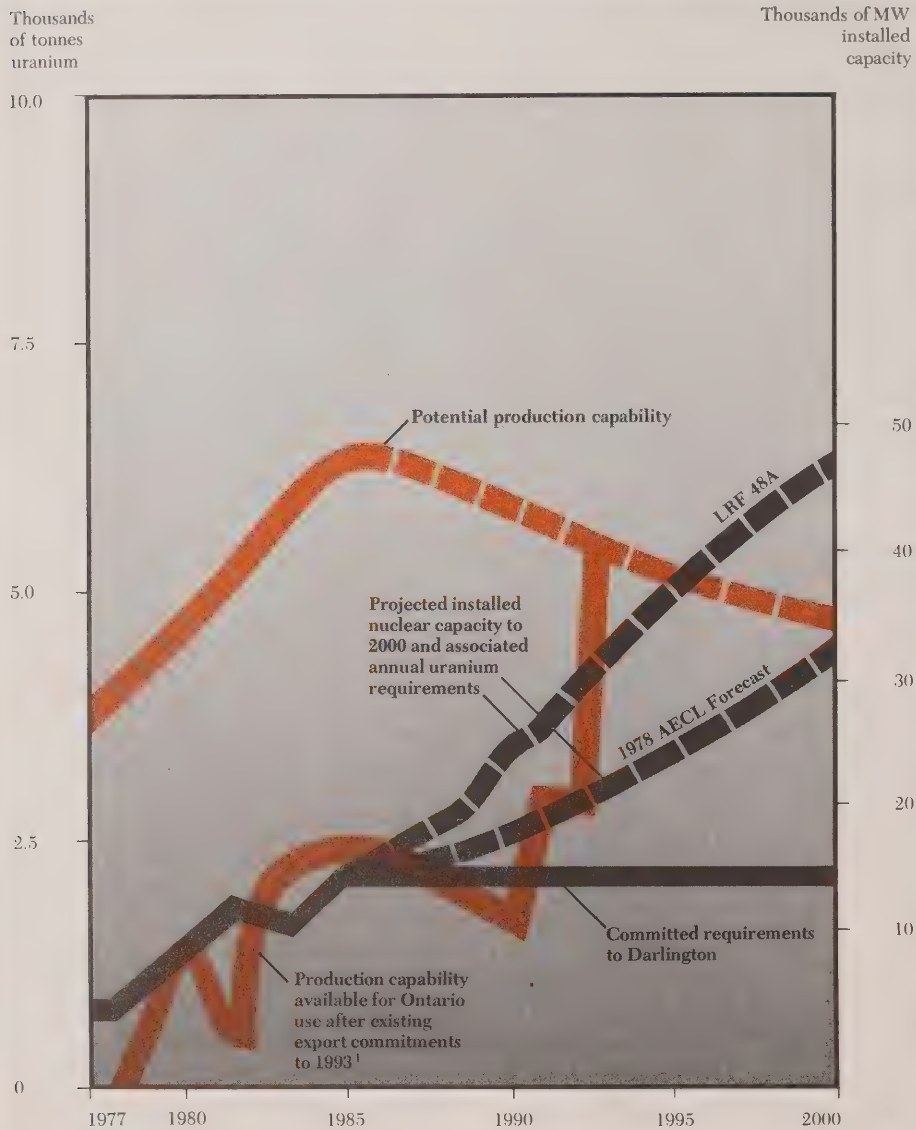
is also a high risk occupation and for that reason may be unattractive to many. Historically, immigration has been a major source of young, often transient, miners for the industry. Recent changes in Canada's immigration regulations, together with projected demographic changes which will result in a decline in the proportion of young men in the labour force in the decades ahead, will therefore present formidable challenges to uranium producers as competition for scarce personnel intensifies in the mining industry. Clearly, extremely costly innovations will be required to attract and keep the required work force in an expanding and often remote uranium industry. Measures which may become increasingly necessary and commonplace include the hiring of more women and working couples, commuting to the mine site, and the construction of elaborate infrastructures and communities similar to those enjoyed by the majority of Canadians in order to attract people who are willing to settle into remote mining jobs for many years.

- Concern over the health, safety, environmental, and social effects of expanding uranium mining and milling operations in particular and the entire nuclear fuel cycle in general (see Chapter 6) has led to in-depth studies and public hearings both by government agencies and by specially-appointed commissions at Cluff Lake in Saskatchewan and at Elliot Lake in Ontario. Even assuming decisions favourable to the uranium industry, such inquiries are time consuming and may delay the attainment of projected production levels. Increased regulatory requirements — particularly the more effective ventilation of mines and the more stringent criteria likely to be applied to tailings containment systems — as well as more comprehensive licensing and approval procedures, which may include mandatory public hearings, could delay production expansion programmes and add to the cost of a project. The decommissioning and abandonment of depleted mines and the long term management of the very large volumes of environmentally hazardous tailings, perhaps in perpetuity, represent extremely difficult issues which may further complicate future regulatory and licensing procedures applied to the uranium industry.
- Unlike other minerals, uranium falls very much under federal government jurisdiction, though it is subject to the same provincial royalties and taxes as all other mineral resources. Canada's and Ontario's expanding uranium industry is dependent upon foreign participation for, in particular, the very large amounts of risk capital which will be required to carry out exploration activities. Future participation may, however, be constrained by federal policies limiting foreign equity. Canada's strict safeguards regime and a federal uranium policy which attempts to protect supply for domestic users create further uncertainty as to whether the uranium found and produced through foreign participation can be exported. If, in addition to these constraints, provincial tax and royalty regimes appear excessive and unattractive to the uranium industry, investors may be increasingly reluctant to commit the large amounts of capital necessary to expand the industry's production capacity.

Figure 9-2 assumes that these not insignificant constraints are overcome and that the maximum potential uranium production based on known, delineated resources is attained in Canada. Figure 9-2 also makes the further unlikely (for reasons discussed below) assumption that no further uranium export commitments beyond those already in existence will be undertaken by Canada. When the potential annual Canadian production capability is compared with the annual uranium requirements of the official growth rate predicted for nuclear units in Canada, it becomes clear that the Canadian supply and demand situation does not appear to be significantly better than the international one. Production shortfalls begin to appear by about 1995 if 82,000 MW of nuclear capacity is in place by 2000, and by 1998 if 60,000 MW nuclear capacity is built. Figure 9-2 again underscores the urgent need to increase exploration activity as quickly as possible since shortfalls in the late 1990s could only be met by production based on new reserves.

Figure 9-3 summarizes the potential for uranium production capabilites indigenous to Ontario and compares this capacity to possible annual requirements in the province, assuming no further export commitments. If a large commitment to nuclear energy — of the sort suggested by Ontario

Figure 9.3 Annual Potential Ontario Uranium Production Capability and Requirements



1 Approximate, as annual delivery schedule is subject to adjustments

SOURCE Based on data from Organization for Economic Co-operation and Development; Energy, Mines, and Resources Canada; and Ontario Hydro

Hydro's Long Range Forecast 48A — were undertaken by Ontario, then annual, indigenous production will be insufficient by the mid 1990s to fuel Ontario's nuclear programme. If a smaller programme is built, under the new AECL forecast which now projects an installed nuclear capacity in Ontario of 31,000 MW by 2000, then production capacity will suffice to about the turn of the century. These developments would imply growing dependence on uranium from outside Ontario, most likely from Saskatchewan. However, based on known reserves, this would provide little relief, since Ontario's annual requirements under LRF 48A would exceed *all* of Canada's potential annual production by shortly after the turn of the century. Thus, the urgency of immediate and extensive exploration is unmistakable. The prospects for success in Ontario are, however, probably more limited since Ontario has already been more extensively explored than other parts of Canada. Indeed, expenditures on exploration in Ontario appear to be declining, from $3 million in 1976 to $2.6 million in 1977.[5] Some of the factors which we have already identified that tend to inhibit exploration activities may therefore be more significant and worthy of attention in the Ontario context than elsewhere in Canada.

Figure 9-3 illustrates two further important points. First and most obviously, a small nuclear programme in Ontario — perhaps an additional commitment beyond Darlington of about 4000 MW — could be fuelled from production indigenous to Ontario to well beyond 2000, assuming no new export commitments. Secondly, export commitments can have dramatic effects on the proportion of potential production capacity that is actually available for provincial use. Existing export commitments in Ontario will, despite the very large uranium contract recently approved by the Government of Ontario, result in some shortfalls for Ontario Hydro until 1993, which will have to be met by production outside Ontario or by accessing the federal stockpile.

Figures 9-2 and 9-3 clearly suggest that for both Canada and more particularly Ontario, large nuclear power programmes will play a major role in supplying our longer term energy needs only if we are prepared to develop and deploy more advanced fuel cycles which will utilize finite uranium resources more efficiently. For example, plutonium recycle would eventually reduce uranium demand by about 30 per cent. A decision to move in this direction would require full and extensive participation by the people of Canada and Ontario to ascertain their willingness to accept the greater risks as well as the benefits implied by advanced fuel cycle technologies. We do not endorse these technologies at this time.

The Export of Uranium

We assumed in Figures 9-2 and 9-3 that no further uranium export commitments would be undertaken. But this assumption almost certainly will not hold; export levels will therefore create further uncertainty as to the availability of uranium and production capacity for domestic use in "once-through" CANDU systems in the late 1990s and beyond, the federal uranium policy notwithstanding. A number of factors lead us to be concerned about this issue:

- The Canadian uranium industry has historically been developed to supply the export market. In the 1950s our uranium was used in nuclear weapons programmes abroad and since the late 1960s Canadian uranium has helped to satisfy the growing international demand for civilan nuclear power programmes. The general recognition that there will probably be little recycling of spent fuel internationally before the 1990s has tended to sustain the demand estimates for uranium despite lower projected growth rates for nuclear power around the world. Shortages could appear by the late 1980s as nations who are deploying large nuclear programmes as an antidote to the OPEC oil cartel move to secure large quantities of uranium on international markets. Canadian uranium producers and provincial jurisdictions with large reserves but foreseeably small or non-existent nuclear power programmes will have an understandable propensity to wish to take advantage of these markets at prevailing international prices.
- Canada will likely continue to be perceived as an attractive, stable supplier of uranium when compared with other major suppliers available to

purchasing nations — the United States, Australia, Niger and South Africa. The United States will require the bulk of its own vast resources, particularly if the reprocessing and fast breeder options are delayed.[6] The geopolitical instability increasingly associated with the African continent will make Niger and particularly South Africa relatively unattractive sources for a resource so strategic as uranium. Australia's large uranium resources may not be exploited for some time — despite favourable findings by a national inquiry and a stated government desire to proceed — because of strong opposition from parts of the country's labour movement, most notably the dockers' unions whose membership has threatened to refuse to ship uranium out of Australia. Even if these political uncertainties can be quickly resolved by an Australia which has no urgent need for uranium domestically since it has no nuclear power programme, it will take a number of years for a sizable production capacity to be put in place.

• The Canadian government is promoting an export oriented uranium industry and has a clear and continuing incentive to do so, in order to maximize the substantial foreign exchange earnings which uranium exports offer and thus offset Canada's growing balance of payments problems, a federal responsibility. Indeed, the Commission has heard the argument from some parts of the nuclear industry that uranium exports could become so important a tool for coping with our balance of payments difficulties that Canada should move as quickly as possible to more advanced reactor systems, based on the recycle of plutonium and eventually the use of thorium, in order to capitalize fully on the international demand for uranium. We do not endorse such a strategy.

• The long term viability of the Canadian nuclear components industry is, in no small way, contingent upon the ongoing export of CANDU reactors, most critically over the next ten years or so. This issue is discussed in greater detail elsewhere in this report. However, this reality could also add pressure for further exports of Canadian uranium. Long term, assured supplies, or at least preferential access to Canadian uranium, could form part of a more attractive "package deal" to secure foreign sales of CANDU units.

• Canada's uranium resources cannot realistically be seen in isolation from the vital needs of our major policial, economic and military allies — the United States, the European Economic Community and Japan — whose energy problems are far worse than our own and whose continued economic well-being and stability is clearly in Canada's interest. Furthermore, the large amounts of foreign capital which will be necessary for the exploration required to make new discoveries and to bring the large quantities of uranium currently in low confidence level categories into the reasonably assured categories, tend to originate in these same nations. Not surprisingly, these foreign investors, once attracted to Canada, will have a propensity to wish to export what they have found to their own domestic utilities, and presumably at prevailing international prices, rather than to supply Canadian utilities that expect to pay a price below that determined by international markets. An overt policy which sought to limit uranium exports unreasonably could, in addition to pre-empting the flow of exploration capital, lead to serious economic and political risks for Canada if applied to our major trading partners. Perhaps an export policy that tied Canadian export levels directly to the rate of new finds and the availability of production capacity, rather than to the resource base estimated to be in the ground, ought to be considered since such an approach would provide direct incentive to increased foreign investment in exploration.

• The demand for large quantities of uranium for domestic use generally and for use by Ontario Hydro in particular will not manifest itself until the late 1990s and beyond if commitments are in fact made to deploy large nuclear power programmes approaching current official forecasts. Indeed, the recent multi-billion dollar forty year contracts between Ontario Hydro and Denison and Preston Mines will satisfy the bulk of Ontario Hydro's annual demand for uranium, the principal Canadian user, for the lifetime of all currently commmitted units or, if an ambitious programme of the type suggested by LRF 48A is committed, until the mid 1990s. Although this situation is clearly favourable to Ontario Hydro's short and medium term interests, it has created a domestic market which will

make it difficult, if not impossible, for other uranium producers to find domestic customers requiring sizable quantities of uranium over the next two decades. With no immediate domestic markets available, producers will seek to export their current allocated domestic reserve to the increasingly lucrative international market. The penalty for doing otherwise would be lost jobs and revenue as well as a decline in exploration activity. This is particularly the case for the high grade, short life uranium deposits in Saskatchewan where, without export customers, all the available uranium could not be mined and sold during the normal economic life of a mine. Canada's current uranium policy allows such a mine to apply for permission to export its allocated domestic reserve if no domestic buyer is available over the last five years of the normal life of a mining operation.

Uranium and the Potential For Self-Reliance

Our evidence and analysis have led us to conclude that Ontario's current nuclear commitment can clearly be based on uranium resources and production capacity indigenous to Ontario. However, in our view, the people of Ontario cannot assume that either the currently delineated uranium resource base or, more importantly, the projected maximum production capacities available to Ontario provincially or nationally are sufficiently secure or sizable to guarantee the long term viability of a large "once-through" nuclear power programme in Ontario beyond the turn of the century. Indeed, as we have indicated, the Canadian and Ontario uranium industries will face formidable challenges if their full potential is to be realized even over the next decade. It is therefore difficult to escape the conclusion that Canada and Ontario share with other industrialized nations the dilemma that if nuclear power is to supply a significant proportion of our energy needs much beyond the year 2000, then a commitment will ultimately have to be made to accept the possible risks implied by advanced fuel cycle technologies based on the recycling of plutonium from existing spent fuel or the breeding of fissile uranium-233 from fertile thorium. The development and demonstration of these technologies will require twenty to twenty-five years and extensive human and financial resource commitments before long term supplies of fission fuels can be reasonably assured on a commercial scale. We cannot, however, endorse these technologies at this time, for reasons discussed elsewhere in this report.

We have further concluded that, although the federal uranium policy appears to strike an enlightened balance between Canadian domestic interests and responsible participation in a lucrative international market vital to the energy requirements of our major trading partners, it is important that the people of Ontario recognize that this policy has important limitations from Ontario's perspective. First, it is silent on the question of uranium prices for domestic users of a Canadian resource and therefore consistent with federal energy policy requiring domestic energy resources to move toward international price levels. It is therefore to be expected that Ontario will in future pay prices determined by the international market for its uranium regardless of origin. Secondly, while current federal uranium policy requires that an approprate portion of uranium reserves be allocated for domestic use to meet utility requirements, the policy is silent on a more critical issue: namely the availability of production capacity for domestic use. Producers may tend to leave their allocated domestic reserve in the ground while producing and exporting higher grade deposits during the next two decades when the domestic market for uranium will be small. These limitations, in addition to the constraints already discussed, suggest that future uranium contract negotiations between producers and utilities will be formidable challenges indeed.

Finally, if uranium is viewed as a tool to provide a measure of self-reliance to Ontario, it should be remembered that jurisdiction over the nuclear fuel cycle rests with the federal government, which has, in Bill C-14 now before the House of Commons, clearly expressed its intention to exercise this responsibility more comprehensively and completely through a regulatory process which will apply more vigorously to uranium mining and milling than has heretofore been the case.

Chapter Ten

Social, Ethical and Political Issues

Nuclear power seems to be a technology which is lacking an appropriate context. It demands a peaceful world, but the world is not as peaceful as we might like. It demands a highly centralized society, subjected to various types of controls, which many people do not desire. It demands a degree of vigilance which is unparalleled, a degree of dedication which is unprecedented, a degree of planning which is unheard of, and a degree of security which is little more than an ambitious hope. Such a technology will inevitably attempt to create the environment which it demands, and in so doing it will have far-reaching implications on all our lives. — *Gordon Edwards and Ralph Torrie, Summary Argument*

THE social, ethical and political implications of nuclear power have been of concern to many who have appeared before the Commission. While no single technology, including nuclear power, has a monopoly on the pressing issues of the day, an assessment of the value of nuclear power from this perspective ultimately requires an examination of the acceptability to society of the risks and benefits of the technology, relative to other options. This process is, by definition, extremely difficult since value judgements of a particularly complex kind, transcending nuclear power per se, are clearly involved. Indeed, whose values are to be judged worthy and how this assessment is to be accomplished with justice are pertinent questions.

Nuclear Power and the "Quality of Life"

In many ways mankind is safer today than ever before. A historical perspective is enlightening. Throughout history, man has had to contend with a variety of natural hazards, infectious diseases, nutritional deficiences and the ravages wrought by his fellow men. Only very recently have our basic needs been met to the extent that we can afford the luxury of being able to worry about more subtle hazards.

Margaret Maxey, speaking at the recent Canadian Nuclear Association Conference, reminded us of what the "good old days" were like: "As we condemn Detroit and auto emissions for making city air unbreathable, let us also remember a New York in 1900 with 150,000 horses in its streets and the emissions they produced." Maxey contends that today's environmental crisis mentality and all the regulatory machinery generated by it constitutes the first problem that needs to be addressed: namely, how is society to exercise some historical and scientific perspective that will result in balanced judgements about alleged environmental hazards posed by advanced technology?

Presentations to the Commission from major industrial concerns praised the high technology society and cautioned against any disruption in the supply of energy. According to the Canadian Steel Industries Construction Council, "the ample supply of relatively cheap electrical energy has been the foundation of Ontario's development as a strong industrial economy over the past fifty years. It has provided a good standard of living for Ontario's people and a high level of employment. . . ."

Abundant energy is clearly the cornerstone of any modern society. And while energy should not be viewed as an end in itself, but rather as one means whereby social, economic and even personal goals can be more readily achieved, the risk of not having sufficient energy at some point in the future is very real. This risk should be weighed in terms of economic disruption and possible political and social instability. E.F. Schumacher, well-known proponent of the "small is beautiful" philosophy, has argued that while growth is an essential feature of life, it must be given a qualitative dimension. Therefore, it is not merely a question of whether or not a particular technology should proceed, but rather how technologies can be selectively employed to maximize and sustain the well-being of society. This proposition, however, brings us full circle to the complex questions and dilemmas of values and judgements. In the words of Ralph Torrie:

> It is impossible to understand the nuclear debate

> without understanding the different world views which underlie the two sides of the debate.... Different world views correspond to different visions of reality.... The world-wide debate on nuclear power has evolved into a debate about the most fundamental values of society.

The Temporal Nature of Nuclear Risks

In the view of many concerned citizens, the use of nuclear energy raises complex new social, political and ethical issues of a profound nature. The physical and temporal dimensions of the risks associated with nuclear power, however small, are particularly disturbing to many. We have heard, for example, the compelling arguement that the risks associated with any technology ought to be assumed by that society since it benefits from the use of that technology. Nuclear power therefore raises a fundamental ethical problem in the view of nuclear critics not only because a nuclear accident might cause genetic damage affecting unborn generations but because the very long-lived, highly radioactive and toxic wastes produced by the nuclear fuel cycle will represent a risk-fraught legacy to future societies who will not have enjoyed the benefits associated with the creation of these wastes. One participant in our hearings commented that nuclear wastes will need to be isolated from the human and physical environment for periods of time surpassing "... any social order humanity has yet devised. Languages, nations, ice ages and species will come and go in that time-frame."

Although the nuclear industry has repeatedly given assurances that a safe method of burying wastes deep underground in geological formations can be achieved, no such demonstrated waste repository yet exists. Of concern to some is the global management of accumulating nuclear wastes and what responsibility, if any, we should assume for the management of wastes produced in Canadian reactors in Korea, Pakistan, India and Argentina. The massive volumes of uranium mill tailings represent an equally formidable challenge to present and future generations. It is for these reasons that we have concluded that progress on the technology of managing these growing wastes should be monitored by an independent group and that a moratorium should be placed on further nuclear plants by 1985, if significant progress cannot be demonstrated.

Without wishing in any way to detract from the very serious nature of these concerns, we must emphasize, in all fairness, that no single technology has a monopoly on such problems. The rapid depletion of many resources, notably petroleum and natural gas, for which all Canadians with their high-consumption lifestyles, must take some responsibility, represents an equally questionable legacy to any future generation whose economic and social well-being and very stability may be at stake. Nor should we become so short-sighted that we destroy our food lands, mismanage our forests, or pollute our watercourses and thereby leave a legacy of environmental degradation to future generations. Other technologies such as the transportation of liquefied fuels, the production of industrial chemicals and pesticides, and the refining and smelting of metals present formidable insults to our environment and to future generations.

Centralization, Public Participation and Civil Liberties

All highly complex and capital-intensive technologies tend to be centrally organized and managed. This trend is increasingly reflected on a "macro" level in the structure of modern societies. While there are obvious benefits associated with the trend to greater centralization, there are also undesirable ramifications, and indeed vulnerabilities, associated with this phenomenon.

While the economic and even the environmental advantages of centralized electrification seem obvious, the sociopolitical costs are less easy to evaluate. This aspect of nuclear power has been criticized as symptomatic of many of the ills and misplaced priorities of modern society. Professor Robert Paehlke commented in his submission to us that:

> Centralized energy sources reinforce centralized economic activity of all kinds and thereby further the tendency of industrialization gnerally to concentrate population, culture, employment, production and so forth ever increasingly. These broad tendencies are in large measure the root of rural depopulation problems, ... and of

> the hinterland-metropolis syndrome so prevalent today . . . nuclear power is at once the logical technical extension and re-extender of this process.

This critique is, of course, not unique to nuclear power, but applies to all centralized technologies. Nor should we forget that the farming community and hence our food supply is heavily dependent on a reliable electrical power system, as Dr. Patterson of the Food Land Steering Committee has reminded us.

All complex technologies require technological "elites" to operate and maintain them. This is at least as true for nuclear power as it is in the computer or aerospace field, for example. However, energy is particularly vital to a nation's life, since most other technologies and industries would be impotent without it and because an increasingly sizable proportion of our social capital will be necessary for such high technology systems as nuclear power. This "elite" therefore exercises, perhaps unconsciously, an enormous amount of power and influence. Furthermore, there exists the very real concern, as our hearings have demonstrated, that only a small technocratic elite can grasp the complexities of nuclear power upon which decisions are frequently based, thereby excluding the public, and perhaps even our political leaders, from meaningful and effective participation in decision-making. Indeed, the interested public is further confused by an array of conflicting views even amongst experts who are in any case frequently perceived to have a vested interest in the nuclear industry.

Two things therefore seem clear to us. First, we must find new and imaginative ways to inform and involve the public in these important issues and decisions. To do otherwise risks unexpected and time-consuming resistance to future projects when the local implications become abvious to affected communities that may perceive a different relationship between the risks incurred and the benefits to be derived than the planners did.

Secondly, we have concluded that if an informed and reasonably sophisticated public involvement in the energy debate is to be achieved, then greater and freer public access to information is essential. This is particularly important in the case of nuclear power where, perhaps because of the historical links of civilian nuclear energy to military weapons programmes, an aura of secrecy still shrouds the contemporary nuclear industry. This aura, together with the quite natural tendency of any industry to promote its products, has often led to public suspicion that unfavourable data are withheld and that the information which is made available by the nuclear industry, which often initimidates laymen because of its technical complexity, is not always objective. If these suspicions are to be allayed and if public trust and acceptance of nuclear power are to be maintained, then the nuclear industry must continue to become more open to public scrutiny.

A concern associated with the problems of centralization and the creation of elites has to do with security measures which nuclear power may require. Ontario's CANDU nuclear power stations represent an economic investment in the order of billions of dollars per facility. Furthermore, the electrical output of any single station is increasingly vital to the well-being of the people of Ontario. The Pickering A station, located 20 miles east of Toronto, for example, currently supplies about one-fifth of the electrical energy generated in Ontario. The security of these facilities against malicious threats which might result in the release of radiation to the public or economic damage and loss of production is therefore a more important concern than might be the case with many other industrial facilities in the province.

This vulnerability will require appropriate security measures. Fundamental civil liberties are fragile, even in the most democratic of countries, and therefore vigilance is required to ensure that they are protected. We have concluded that the security measures now in place or contemplated in Ontario as a result of a once-through CANDU programme do not limit our civil liberties. However, if the reprocessing and recycling of plutonium or uranium-233 were to be commercially undertaken in Ontario — and we do not endorse such an initiative — we would agree that the security measures that would then be necessary might present serious threats to our civil liberties.

The Politics of Nuclear Power

Those who undertake an activity or receive the benefits of an enterprise are not always those who are subject to the risks which are generated by the process. The front- and back-ends of the nuclear fuel cycle, which create perhaps the most significant hazards — the mining and milling of uranium and the disposal of nuclear wastes — tend to be conducted in the less populated and more remote "hinterland" of Ontario but predominantly serve the demands of the distant and urban population in the south. We must question whether any segment of a society, even if it is the majority, has the right to impose disruptions elsewhere in society. We believe strongly, for example, that the rights and privileges of certain sectors of our society and their ability to maintain their preferred lifestyle in the face of large scale developments such as nuclear facilities should be preserved and protected. The siting of such facilities on prime farmland is equally disturbing and should, in our view, be discouraged. Failure to take the concerns and sensitivities of minority sectors of our society into account, particularly if they are implicitly going to bear a disproportionate part of the risks of the nuclear fuel cycle, can only result in confrontation in the future.

Chapter Eleven

Nuclear Weapons Proliferation and Plant Security

The consequence of nuclear power that dominates all others is the attendant increase in the number of countries that will have access to the materials and technology for nuclear weapons.
— *Ford-MITRE Report* (p.271)

FROM time to time during the Commission's hearings the relationship between civilian nuclear power on the one hand and nuclear weapons programmes on the other was raised. The avoidance, to the greatest extent possible, of further nuclear weapons proliferation is in the interest of all members of the world community. It is a problem for which responsibility must be shared by all. We believe the achievement of this goal must begin, as in other areas of human endeavour, with the recognition by the public, governments and the civilian nuclear industry that the problem exists. Only then will resources be devoted to coping with this technically and politically complex question. Canada, because of its role in the international civilian nuclear market as a supplier of uranium and reactors, has a clear responsibility to continue to strive for ways to limit proliferation and is doing so. Ontario, the major domestic producer and user of nuclear technology and materials, has a responsibility to support and facilitate these efforts.

Although the subject is peripheral to our mandate, we believe we have a responsibility at least to attempt to put this complex and controversial problem into perspective.[1] The better the understanding of the proliferation problem amongst the public, policy-makers and the nuclear industry, the more probable it is that an acceptable solution will be found. Indeed, we believe that public recognition of the importance of the proliferation issue may be an important catalyst to the further development and acceptance of political and technical initiatives such as the adoption of reactor and fuel cycle configurations that are less likely to contribute to proliferation.

In this Chapter we consider nuclear weapons proliferation and security at Ontario Hydro's nuclear facilities.

Canada and Nuclear Proliferation

Although Canada appears never to have contemplated the manufacture of nuclear weapons, this country not only participated in the research which gave birth to the original atomic bomb (see Chapter 4), but also, through the export of strategic material, subsequently facilitated their production. For example, the bulk of the uranium mined at Elliot Lake, Ontario, in the late 1950s and early 1960s, was used in the production of nuclear weapons in both the United States and Great Britain.[2] It was, however, the detonation of a nuclear device by India on May 18, 1974, the fissile material (plutonium) for which was reportedly obtained from a Canadian-designed and -built research reactor, which jolted the sensibilities and perceptions of people around the world. The realization that the development of nuclear energy for peaceful purposes is largely inseparable from the development of nuclear weapons (because the same basic materials, facilities and expertise are involved in both) was dramatically brought back into focus. It had, of course, been recognized for many years, not least by nuclear scientists and engineers, that the civilian and military uses of nuclear power were closely related.

Technically, the requirements for the production of a nuclear device are two-fold: first, a sufficient quantity of fissile material to develop a "critical mass" must be available;[3] secondly, the technological know-how and ancillary materials and equipment to build the nuclear device must

exist. Unless comparatively pure fissile uranium or plutonium are available (for a clandestine operation this is improbable), these materials would have to be extracted from "spent reactor fuel". Two highly sophisticated problems would have to be solved: first, spent CANDU fuel bundles must be diverted from a generating station;[4] secondly, the handling, transporting and reprocessing of the spent fuel must be accomplished. While it may be difficult to overcome these obstacles, we have no doubt that both the diversion of spent CANDU fuel and its subsequent processing to produce plutonium are real possibilities; a well-financed group of experienced scientists and engineers could probably undertake the task. The design principles for the manufacture of a nuclear bomb have already been published, together with the properties of nuclear weapons. Furthermore, the chemistry and metallurgy of uranium and plutonium have also been treated extensively in the scientific literature. Therefore, we believe that a government, already operating nuclear power stations, could divert fissile materials and design and produce nuclear bombs.

A crucial question, however, is: If a nation possesses a CANDU nuclear power station, and wants to build a nuclear device, would CANDU spent fuel be the most likely starting point? It has been demonstrated that the plutonium component in CANDU spent fuel, especially when irradiated for a comparatively short period, is "bomb quality", although not necessarily "high yield bomb" quality. A recent article notes that there are several other options, which could be followed by a nation seeking bomb materials, that do not employ power reactors:[5]

- obtain or build a research reactor as well as a small reprocessing plant. Indeed, most nations that possess nuclear power stations are likely to have established a research reactor facility as part of their nuclear power programme;
- dedicate a small reactor exclusively to plutonium production and build a small reprocessing plant;
- enrich natural uranium using the comparatively recently developed centrifuge, laser, or "nozzle" techniques if they are available;
- purchase on the "black market", or otherwise obtain highly enriched uranium or plutonium.

The first two of these techniques probably offer quicker and cheaper access to fissile bomb material than diverting, handling, transporting and reprocessing spent CANDU fuel. Nevertheless, the availability of other options does not preclude the possibility that CANDU reactors might be used by some nations to divert and obtain plutonium, since it is technically feasible. Therefore, the stringency of Canada's nuclear safeguards policy should not be diminished.

The attempt to limit the spread of nuclear weapons is based on several international agreements of which the most recent and comprehensive is the Treaty on the Non-Proliferation of Nuclear Weapons (NPT). This treaty, which came into force March 5, 1970, has been endorsed by over one hundred nations. Notably, however, Argentina, India and Pakistan, among thirty-nine states, have not signed the Treaty; nor, for that matter, has France, although she accepts most of the provisions of the Treaty. Nevertheless, "virtually all the nuclear facilities in the territory of non-NPT parties are subject to non-weapons pledges and safeguards as a condition for obtaining fuel or equipment from the suppliers."[6]

In large measure the NPT is based on the International Atomic Energy Agency (IAEA) Statute, relating to the prevention of the spread of nuclear weapons, which was signed in 1956. The objectives of the Statute are as follows:

> The Agency shall seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world. It shall ensure, so far as it is able, that assistance provided by it or at its request or under its supervision or control is not used in such a way as to further any military purpose.

The NPT calls for non-nuclear weapons states to forgo the development of weapons in exchange for complete access to scientific information on the peaceful uses of nuclear energy. The Treaty also calls for a high degree of co-operation between the signatories, to advance further the peaceful applications of nuclear energy. In principle these agreements and formal treaties to limit the spread of nuclear weapons cannot be criticized. The key

problem lies in how the safeguards provisions to which all signatories of the NPT are committed are interpreted and enforced. As several participants in our inquiry have put it — "these treaties and agreements have no teeth". The IAEA, which both promotes the peaceful use of nuclear energy and administers NPT safeguards, is increasingly forced to rely on national inspection systems, and hence, on the goodwill and co-operation of a host country. Moreover, since the safeguards inspection information is regarded as confidential, the world community will not in fact know how effectively the safeguards are being applied. No existing safeguards systems carry effective sanctions or enforcement provisions. Withdrawal from the NPT can be accomplished on tendering three months' notice. These problems notwithstanding, international treaties are not broken lightly by most nations. While by no means a panacea, safeguards will slow and in some cases deter proliferation by raising the risk of detection and exposure. They will not, however, by themselves guarantee that nuclear materials will not be diverted for military purposes.

Because the growing international markets in nuclear materials and technologies continue to provide expanding opportunities for weapons proliferation, the so-called London Suppliers Group (of which Canada is a member) is attempting to achieve agreement amongst the principal nuclear suppliers to enforce more stringent bilateral safeguards on their exports. In addition, two important programmes have been set up over the past year: the International Fuel Cycle Evaluation Programme (a result of the London Economic Summit of 1976), and the Non-Proliferation Alternative Systems Assessment Programme. These programmes aim to assess fuel cycles that minimize access to materials directly usable in nuclear weapons.

The CANDU system clearly possesses technical characteristics which offer opportunities to divert spent fuel to possible use in the production of nuclear weapons. For example, its unique on-line fuelling capability makes diversion of spent fuel more difficult to detect, since constant surveillance would be necessary to monitor the movement of fuel through the reactor and into spent fuel storage bays. On-line fuelling also facilitates the production of higher quality weapons-grade plutonium (less Pu-240) than is the case with LWRs, since specific fuel bundles can be irradiated for shorter periods. There is little doubt, therefore, that a nation possessing a CANDU reactor might divert spent fuel without detection, and subsequently extract weapons-grade plutonium in a small scale reprocessing facility. Much more rigorous international safeguards are clearly desirable but will be difficult to achieve. In the current absence of effective sanctions against violators, safeguards will at best buy time in the race against nuclear weapons proliferation.

The recently completed Windscale Inquiry in Britain may have some relevance to Canadian concern about proliferation.[7] The Inquiry, headed by the Hon. Mr. Justice Parker, was concerned essentially with an application by British Nuclear Fuels Ltd. to build a reprocessing plant to reprocess foreign spent fuel. For many years a reprocessing plant has been operating at Windscale in northwest England, not without various incidents, to handle the spent fuel from Magnox reactors. Bearing in mind that neither Ontario Hydro nor the Commission is advocating the development of a commercial spent fuel reprocessing plant in Canada during this century, we draw special attention to two of Mr. Justice Parker's major conclusions:

> 6.32 Returning the plutonium to non-nuclear-weapon owner countries will represent an increased risk, but this might be mitigated by returning only when required for civil reactors and then only in the form of briefly irradiated fuel rods.
>
> 6.33 Whether this risk, which will not arise for at least ten years, is or is not a greater risk than the increased incentive which the denial of technology and facilities would immediately create, is a matter for the Government and depends amongst other things on information on the reactions of other countries to the policy. The argument that the grant of permission would add to proliferation risks was not however established before me. Indeed I would go further. Since (i) there will be no direct risk arising from THORP (Thermal Oxide Reprocessing Plant) for at least ten years (ii) to deny reprocessing would be against the spirit — and I think the

> letter — of our obligations under the main existing bulwark against proliferation (iii) the denial of such facilities would create an immediate incentive to others to develop their own facilities (iv) there is a world need for adequate reprocessing facilities somewhere, it appears to me that a grant of permission would have a non-proliferating effect rather than the reverse. I do not accept that the best way to achieve a new bargain is to break an existing one.

Clearly, Mr. Justice Parker and his colleagues, after considering the evidence on the nuclear proliferation issue, have concluded that the proposed major reprocessing plant at Windscale will contribute negligibly to nuclear proliferation among non-nuclear nations. We have come to a similar conclusion and believe that the risk of nuclear weapons proliferation due to Ontario Hydro's CANDU power stations should be regarded as minimal. On the other hand, the future export of Canadian nuclear technology and materials could indeed lead to a degree of proliferation, and, with Mr. Justice Parker, we believe that the assessment of this risk must rest with Government. It is encouraging to note that, even at risk of commercial disadvantage, Canada is enforcing perhaps the most stringent safeguards system in the world.[8]

Security at Ontario's Nuclear Facilities

Ontario's CANDU nuclear power stations represent an economic investment in the order of billions of dollars per facility. Furthermore, the electrical output of any single station is increasingly vital to the well-being of the people of Ontario. The Pickering A Station twenty miles east of Toronto, for example, currently supplies about one-fifth of Ontario's total electrical requirements. The security of these facilities against possible economic damage or loss of production due, for instance, to malicious disruption by individuals or organizations is therefore more important than might be the case with many other industrial facilities in the province.

Many large, modern industrial complexes — petrochemical refineries, for example — represent a risk to public safety if individuals, particularly those with malicious intentions, were to gain unauthorized entry to such facilities. Indeed, if sabotage is the objective, for whatever motivation, there are clearly a great many possible targets available in modern societies, most of which could be attacked with relative ease and often with catastrophic results.

In terms of significant potential hazard to the public, nuclear power presents essentially two security problems:

- to deter an unauthorized diversion of radioactive or fissile materials for possible use in the fabrication of a nuclear device or a plutonium dispersal weapon
- to deter sabotage or threats of sabotage against a nuclear reactor or reactors by politically motivated terrorist groups, criminals or individuals whereby some portion of the very large inventories of radioactive material available in the core might be released to the environment.

Diversion of fissile or radioactive materials is not a serious problem at this time in Ontario. Theft of plutonium-bearing spent fuel from station spent fuel bays is generally not considered to be a credible threat. Spent fuel is highly radioactive and therefore requires special shielding and handling equipment if it is to be moved. Removal of the plutonium in the spent fuel would require relatively complex and time-consuming chemical separation. The diversion of spent fuel during transport appears equally unappealing, since transport casks containing spent fuel are highly destruct-resistant and weigh tens of tonnes. However, since highly enriched (95 per cent) uranium is used in the "booster rods" at Bruce A and since significant quantities of strategic nuclear materials have come into Ontario over the years for research purposes,[9] continued vigilance and strict adherence to IAEA safeguards concerning these materials will be important. In the event that large scale research programmes or commercial development of plutonium or thorium fuel cycles are undertaken, the security problems associated with the diversion of fissile materials such as plutonium or uranium-233 will assume great importance. At this point in Ontario's nuclear programme, however, the only credible security concern is sabotage against nuclear installations.

This problem arises not so much from the existence of nuclear power per se, but from the disturbing global growth of terrorism over the past

decade and the simultaneous escalation in the sophistication of the tactics and weapons available to terrorists. The vulnerabilities of modern society and the availability of powerful and highly portable weapons have given progressively smaller groups the capacity to cause serious disruption or destruction. While terrorist activity is relatively infrequent in Canada, it does seem prudent to assume that nuclear power stations may be regarded as attractive targets by terrorists in the future. The spread of nuclear facilities will increase the opportunity for some type of nuclear action by terrorists. If the confrontation between governments and terrorists continues to escalate, terrorists may be forced to seek higher leverage targets — in the political and the psychological sense. The risk exists, but clearly cannot be quantified.

The objective of terrorism is to create immediate, dramatic effects — unfortunately often through violence. We believe it is precisely this objective that may make nuclear terrorism appealing. The very mention of the word "nuclear" frequently generates visions of "mushroom clouds" in the collective unconscious. It is this phenomenon which is exploitable.

If a determined terrorist group with an established record of violence were to take over a nuclear station and threaten to cause the release of significant amounts of radiation unless certain conditions were met, the event would clearly command immediate and world-wide attention and would almost certainly create widespread panic and fear among the local population. The authorities charged with the responsibility of dealing with such situations would be called upon to make very rapid and complex decisions. They would have to weigh the technical credibility of the threat (which might be very low unless the terrorist group displayed in-depth knowledge of nuclear plant design and operation), the apparent willingness to carry out the threat (this could be high) and finally, the magnitude of the damage if the threat were successfully carried out (this could be very high), at least to the plant if not also to the surrounding area, population and environment. Needless to say, the outcome of a first incident of this type, if it were to happen, would significantly affect management of any future incidents which might follow. Indeed, even the threat of an attack on a nuclear facility might subsequently put considerable pressure on governments to acquiesce to terrorist demands.

In light of these concerns, the Commission and senior staff have toured nuclear plants in Ontario. Further, we held special hearings *in camera* on these matters and heard the views of several members of the public as well as Ontario Hydro and the Atomic Energy Control Board (AECB). A representative of the Ontario Provincial Police was also in attendance as an observer.

The AECB's general licensing procedures for nuclear facilities require that the applicant submit security policies and procedures before approval is granted. These policies and procedures are evaluated by the Protective Services Group of the AECB with assistance from the Royal Canadian Mounted Police, and must cover the security of nuclear materials in use, transit, or storage, the security of nuclear facilities, the training of reliable security staff, the protection of information relevant to the security of nuclear materials and facilities, and the development of contingency plans in the event of a serious incident which would compromise security.

Although some members of the nuclear community have argued before this Commission that the threat represented by nuclear sabotage is "imaginary", the AECB clearly has taken the position that, while the probability of terrorist attacks on nuclear facilities is low in Canada, Canada cannot consider itself immune from such events. The AECB therefore acknowledges that the need for security has arrived. It is recognized that the intrinsic design and operating features of a nuclear station — the massive structures, the numerous barriers to release of radiation to the environment and the redundancy built into critical systems, for example — provide a considerable degree of security against attempts to put a reactor into a catastrophic mode or to release significant amounts of radioactive materials to the public. Indeed, it should be an important priority of future reactor design to improve further these intrinsic qualities. Nevertheless, an upgrading of physical security is under way at Ontario Hydro nuclear facilities.

We are satisfied that these new measures —

which include 360-degree fences, electronic perimeter surveillance, alarm systems and secure communications with local law enforcement agencies — are appropriate for current conditions, and will give Ontario Hydro considerable capability to deter and detect unauthorized intrusion at its nuclear facilities. We have concluded, as has the AECB, that armed guards are neither necessary nor desirable. Armed response should, if necessary, be the responsibility of local and provincial police forces, supplemented in extreme situations by the military. It will be important and prudent, however, to maintain the ability to respond quickly to changing social and political conditions with due regard to civil liberties.

We are not convinced that the responsibilities for all facets of security and contingency planning at nuclear plants in Ontario are clearly defined and understood by all relevant agencies. Since the capability to respond effectively and quickly if unauthorized intrusion is taking place is of paramount importance, particularly the first time an incident takes place, we have concluded that a comprehensive crisis management system incorporating police and political authorities should be designed and available to deal with the complex and rapid judgements and decisions which a nuclear incident might make necessary. The demonstrated existence of such a response capability might prove to be a considerable deterrent to threats or incidents involving Ontario's nuclear programme.

Chapter Twelve

The Regulation of Nuclear Power

GOVERNMENTS, on perceiving that risks from an activity may exceed the benefits, often establish a system of regulation to protect an affected group. They have, for example, implemented regulatory mechanisms where monopolistic conditions exist in order to provide economic protection and to ensure satisfactory levels of service at fair prices. Likewise, they have established licensing and enforcement procedures to guard the health or safety of man and his environment from potential risks. Nuclear power is an enterprise which governments on a global basis have determined should be subject to a system of regulation.

The regulation of nuclear power is, however, distinctive in that it occurs in an environment of continuing and perhaps growing public concern and divided opinion over the risks and benefits associated with the technology. It is a complex technology understood by only a select few technocrats, and it is a centralizing technology which implies a form of social and economic development which does not find universal acceptance. In Canada, the regulation of nuclear developments is further complicated by the extensive public ownership of the corporations which have designed, developed and are utilizing the technology,[1] by the uncertainties associated with the allocation of regulatory responsibility, and by the economic advantage which could possibly accrue to Canada from the development of all aspects of the nuclear fuel cycle.[2] Complex as it is, the continuing challenge afforded by the necessary rigorous scrutiny of nuclear power was captured at the Fourth International Conference on the Peaceful Use of Atomic Energy, held in Geneva in 1971, by Alvin M. Weinberg and Philip Hammond, both active for a number of years in the development of nuclear power when they stated:

> We in the peaceful nuclear energy community have been comfortable in the belief that what we have wrought over the past 30 years has been an unmitigated blessing for mankind. It comes as a disconcerting shock, therefore, to find that, just when nuclear energy has achieved such great success, our effort is being challenged on the most fundamental grounds. Where we claim nuclear energy is clean, safe, and necessary, critical voices claim it is unclean, unsafe, and unnecessary.
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> We have always conceded that, in opting for nuclear energy, mankind is assuming a certain risk. Nuclear energy is potentially more dangerous than other forms of energy. It is only by scrupulous attention to detail, an exertion of great care, that we can expect to maintain the safety of nuclear power.[3]

Regulation in an area where there is deep polarization of opinion will continue to be difficult, since it is conducted against a background of differing expectations of the regulatory process that parallel the variety of perceptions of nuclear power. The nuclear industry and Ontario Hydro, for example, approach the regulatory process as an educational and consensus-building activity. Their testimony at the Commission's hearings leaves the impression that, despite the frustrations of the administrative delays of regulatory processes, they will be able to alleviate most concerns and thus develop a consensus that nuclear power is acceptable. The opponents of nuclear power appear to approach the regulatory process with one major objective: to develop a more open process that will

allow them to question continuously the need for this complex technology, the possibility of accidents, waste disposal problems, sabotage, and terrorism.

Despite their differing views both the proponents and the critics of nuclear power assert that changes in the regulatory process are necessary. The proponents assert that regulatory reform would shorten the lead time required for a project and remove jurisdictional uncertainties, while critics counter that revisions are needed in order to increase openness, improve the accountability of regulators, and increase opportunities for more and earlier public involvement.

Today, the control and supervision of most aspects of the nuclear fuel cycle in Canada are, as they have been since 1946 with the passing of the Atomic Energy Control Act, the responsibility of the federal Atomic Energy Control Board. However, the Board's jurisdiction over health, safety and security in nuclear programmes is only a portion of the extensive system that governs the development of nuclear facilities in the province of Ontario.

Because Ontario Hydro is a publicly owned corporation, operating under The Power Corporation Act, land acquisition for and construction of its major facilities, including nuclear and heavy water plants, requires explicit approval by the provincial government. The financial and economic implications of Ontario Hydro's nuclear programme are regularly reviewed in public hearings by the Ontario Energy Board (OEB), functioning as an advisory body to the Ontario Ministry of Energy. These hearings are undertaken to review applications by Ontario Hydro for increases in bulk power. On one occasion in 1974, the Board was asked to review Ontario Hydro's proposed system expansion programme to 1983, focussing on the need for additional nuclear stations known as Pickering B, Bruce B and Darlington. Public hearings were accordingly held during the winter and spring of 1974. The social, environmental, and economic effects of nuclear power are also reviewed at the planning, development, and operational stages by a variety of other federal and provincial agencies. Thus the nuclear regulatory process is — perhaps of necessity — complex and multi-jurisdictional. It requires co-operation, co-ordination, and consultation among the regulators and has occasioned the formation of both *ad hoc* and ongoing committees, and the development of inter-agency agreements.

In this Chapter we cannot, of course, address all aspects of the extensive system of regulation. Many of the regulatory issues are pervasive, requiring further debate in our decision-making hearings and, therefore, will be most appropriately dealt with in our final report. However, we consider the regulation of health, environment, safety and security matters with specific reference to jurisdictional uncertainty, the regulation of a complex technology, access to information and public participation. And in the concluding portion of the Chapter we address, in a general manner, decision-making on the "need" for nuclear power, a question which is being brought increasingly to the attention of regulatory bodies in both Canada and the United States.

The Regulatory System

The task assigned to the Atomic Energy Control Board to regulate, license and monitor all aspects of the nuclear fuel cycle is enormous. Under existing legislation the Board's functions are to:

- regulate the health, safety, and security aspects of prescribed substances[5] and nuclear facilities;
- provide technical advice about and administer certain aspects of Canadian policy and international commitments on the safeguarding of certain prescribed substances and nuclear equipment for peaceful purposes;
- provide advice on policy development and administration of certain aspects of Canadian policy on uranium resource management;
- protect certain atomic energy information and oversee security classification in the area;
- contract for mission-oriented research in the broad field of nuclear safety.[6]

The functions of the Board are carried out by an authorized full-time staff of 180 with an annual budget of $7.3 million. In the current year, the Board administers a supplementary budget of $5.6 million for the continuing investigation and clean-up of various sites in Canada that have been contaminated with low-level radioactive materials. Because its staff is small, the Board relies heavily on

thirteen advisory committees, which are composed predominantly of representatives from federal and provincial departments of health, environment, and labour; academics from a variety of disciplines; Board staff; and nuclear experts from AECL's Whiteshell and Chalk River laboratories.

For projects which are federally financed, or in which federal agencies are involved, public hearings are held under the federal Environmental Assessment Review Process (EARP). Recently, for instance, hearings were held in connection with the Eldorado Nuclear Limited proposed uranium refinery expansion in Port Granby, Ontario.

Ontario regulatory authorities have become involved in the nuclear power area through the application of general provincial legislation on environmental, health, resource development, and energy matters. Their involvement extends to several facets of the nuclear fuel cycle in addition to Ontario Hydro's thermal nuclear programme, including uranium mining and refining developments.

Provincial regulatory authorities exert their influence indirectly through involvement on advisory committees or through administrative understandings with the AECB. For example, through membership on appropriate safety advisory committees, representatives of provincial government ministries are able to enunciate provincial policy and regulations that can be incorporated into AECB licences.

The nuclear programme in Ontario is also indirectly affected by numerous international advisory and regulatory agencies (see Annex D). These include the International Atomic Energy Authority (IAEA), the Nuclear Energy Agency (NEA) of the Organization of Economic Co-operation and Development (OECD), the International Commission on Radiological Protection (ICRP), the United Nations Standing Committee on the Effects of Atomic Radiation (UNSCEAR), the International Radiation Protection Association (IRPA), the Nuclear Suppliers Group and the International Joint Commission (IJC).

These agencies rely on member countries to accept and apply internationally agreed-upon standards such as those governing radioactive doses for workers and the general population, nuclear safeguards, and transportation of radioactive fuels. Where applicable, the AECB accepts and applies existing international standards in the licensing of nuclear facilities. In particular, the AECB relies heavily on ICRP radiation guidelines. In future, we anticipate that international regulatory agencies will increasingly influence the Ontario programme. One recent example is the new suggested levels for radioactivity in the Great Lakes, proposed by the IJC, which, if adopted by either the federal or provincial environment ministries, could affect both uranium mining and the nuclear reactor programme considerably.

Recent Developments

In its first twenty-five years, the AECB functioned quietly in the background of a nuclear industry that attracted little public attention. However, with the acceleration of the Ontario nuclear power programme and the publicity given to the potential hazards of the nuclear fuel cycle, the Board became the focus of demands for increased regulatory vigilance. Following its investigation, the Royal Commission on Health and Safety of Workers in Mines recommended that the AECB should exercise its authority over the *total* fuel cycle.[7] With the controversy over the health hazards of radon associated with wastes from the earlier Eldorado refinery at Port Hope there was a call for better communication between the regulators and those whose health is potentially affected. In recent months there has been increasing public demand for access to information held by the nuclear industry, for more public participation in nuclear regulatory decisions, and for greater separation between the regulators and those associated with the promotional aspects of the industry.

In response to these and other concerns, the federal regulatory process is now in the midst of a significant transition. The AECB is attempting to widen the gap between itself and the industries and utilities regulated, and to improve its capability to license and monitor the industry. Indeed, the complement of the Board has more than doubled in the last three years, and may possibly double again in the near future. Also of considerable significance are the measures taken by the federal government to increase the Board's effectiveness. In an effort to

update the nuclear regulatory framework, the Nuclear Control and Administration Act (Bill C-14) was tabled on November 24, 1977. Although this proposed legislation has not yet been enacted, it indicates clearly the government's intent for proposed changes in federal regulation. Much of Bill C-14 contains a detailed amplification of the general terms of the existing Atomic Energy Control Act,[8] and the remainder is new. The overall result is extensive powers for control of nuclear developments throughout Canada. A Nuclear Control Board would be created to replace the Atomic Energy Control Board, and its objectives would be to "ensure the preservation of the health and safety of persons and to protect the environment from the hazards" of the use of nuclear power. Provisions are made for licensing, including hearings for licence applications; access to information; inspection of nuclear facilities; and making regulations.

During the present period of controversy and change, concerning federal nuclear regulation, the provincial regulatory authorities have become increasingly involved in the issues of nuclear power development. For example, the Ontario Ministry of the Environment has noted that "the debate over safe nuclear standards ensures no small degree of controversy for the Ministry in its approval and abatement processes incorporated in AECB licences".[9]

The most significant recent provincial legislation affecting the nuclear programme in Ontario is the Environmental Assessment Act. The Act is intended to encourage "good" decision-making by ensuring that environmental factors are taken into account at an early stage. It provides that an environmental assessment must be accepted, and approval given, for all undertakings to which the Act applies – which will include all future Ontario Hydro generating stations.[10] As part of this process, Ontario Hydro must provide a statement of the rationale for the undertaking, alternatives to the undertaking, and alternative methods of carrying out the undertaking, as well as a description of probable environmental impacts of the undertaking and its alternatives. "Environment" is broadly defined to encompass social and economic aspects as well as the natural environment. The environmental assessment document and the government ministries' review of it are available to the public, and public hearings by the Ontario Environmental Assessment Board can be required.

Jurisdiction – the Allocation of Responsibility

We perceive potential difficulty and uncertainty about the division of legislative powers over nuclear energy between the provincial and federal governments, especially in the environmental assessment area. The power of the federal government to regulate developments for the purpose of protecting health, environment and safety is apparently well established. We believe that this allocation of responsibility is appropriate.[11] However, we also believe that since nuclear development is a provincial undertaking the province should have the responsibility to make the choice to use nuclear power and the decisions concerning its environmental, social and economic costs.

Difficulties may arise because the application of statutes enacted by each government may conflict. For example, the requirement of approval and the imposition of conditions under the Environmental Assessment Act may conflict with approval to construct a nuclear power plant given by the Atomic Energy Control Board. If a conflict does occur, the federal statute would be paramount, and the provincial statute would be inoperative. However, the determination of the existence of such a conflict and its consequences is a difficult issue of constitutional law, and prediction is a precarious undertaking even for constitutional experts. Co-operation between federal and provincial authorities is needed to avoid delay, expense, and uncertainty about the allocation of responsibilities. One of the possible avenues for co-operation is Bill C-14, which permits the Nuclear Control Board to enter into agreements with Ontario Ministries for compliance and inspection services; to incorporate provincial laws by regulations; and to make compliance with provincial laws a condition of a licence. If it is enacted we encourage the making of appropriate agreements.

The Regulatory Process

Standards setting, licensing and monitoring of such a complex technology as nuclear power are based on scientific analysis, experimentation and probability theory. In balancing the benefits against the potential risks the regulator must often make a choice between a range of interrelated alternatives. In making such choices the AECB relies on the evaluation conducted by a small cadre of experts within the Board as well as the independent input from its many advisory committees. The Board's staff can often bring a global perspective to a decision because they have developed close working relationships with experts associated with other international regulatory agencies. On the other hand, many members of the advisory committees are closely associated with the nuclear industry and therefore can bring to the attention of the Board the economic implications as well as the safety implications of a pending decision. The Board weighs both inputs but it is important to note that, to date, no facility or process has been licensed or new standard accepted without an affirmative recommendation from the appropriate advisory committee.

The Board (i.e., regulator) is often criticized for considering costs when evaluating health, environment and safety measures. We do not endorse such criticism. While the regulator must be vitally interested in the preservation of nuclear safety there must be a conscious awareness of the economics of the measures being proposed which must be balanced against the risks that are being averted.[12]

The complexity of the technology and the engineering, scientific, and medical research and evaluation that must be conducted require the knowledge and skills of experts in nuclear matters. Given the limited number of nuclear experts in Canada, we accept that a close working relationship must exist between the regulator and the regulated. Moreover, the closed Canadian regulatory approach has fostered frank discussion between the regulator and the regulated, and has led to positive resolution of health and safety issues. We have no doubt that the Canadian public has been well served by decisions which led, for example, to the development of stringent Canadian requirements for dual safety systems and containment structures. We are also convinced of the ongoing vigilance of the AECB and its committees on safety matters and of their commitment to improve safety criteria. The advisory committees have been a major strength of the Canadian regulatory process and should be continued.

As the debate on nuclear regulation unfolds we suggest that the focus may shift, and the challenge will be to design institutions and procedures that respect the expert, allowing him to research and develop decisions, but which at the same time permit the testing and control of these decisions and, in particular, demand accountability. We will be exploring this and related topics further in our final report, including the application of Delphi techniques and the science court approach to decision-making.

We endorse the general principle of "openness" of the regulatory process. Openness encompasses many possibilities, from more detailed explanation of reasons for decisions to broader involvement in decision-making. A pervasive issue is the availability of information on the health and safety implications of nuclear power. We are aware of efforts by the nuclear industry to develop and distribute helpful information to the general public. The AECB itself is accepting a central role as a source of independent public information. However, although some types of information are available in over-abundance, there are increasing demands for access to detailed technical material (often of a "preliminary" nature) now available only to the industry and to the regulators. The Commission's view on access to information is that disclosure should be the rule, and exceptions should be sharply limited. During the course of our hearings, for instance, we reviewed the Bruce and Pickering Safety reports, a postulated loss-of-coolant accident report, the Bruce Reactor Safety Notes, and quarterly operating reports, and concluded that on safety or security grounds there is no apparent reason to withhold this information, except that relating to floor plans, for example, from the public. The information should also be conveniently accessible: some of the documents mentioned above were in fact available but at restricted locations, and their availability was not generally

known even to groups actively involved in the nuclear debate.

Public participation is increasingly being recognized as an essential component of decision-making on nuclear matters. Much of the work of the scientific and engineering community has been and will increasingly be subject to public scrutiny. We endorse this direction, because we believe that although the details of experts' decisions may be comprehensible to only a few, many of the uncertainties of risk analysis and many of the choices to be made can and should be more fully explained to the general public, and should receive the benefit of public input. But caution should be exercised in our expectations of public participation. Decisions will still require technical and scientific data and recognizing this fact, there must be a careful development of the appropriate purposes, timing and procedures for public participation. We will be giving further consideration to this subject in the remaining sections of this chapter.

Standard Setting

The AECB has extensive knowledge, based on experience, relating to the design of nuclear facilities, but most of this has not been expressed in writing. Consequently, many of the rules, design standards and licensing criteria have existed only in the minds of the staff of the Board, the staff of the utilities and the members of the advisory committees. This lack of clear written statements has led to considerable debate between the regulator and the licensee (e.g. Ontario Hydro) on the intent and limitations of the standards. Recently the Board has begun to document rules and guidelines for all aspects of the fuel cycle.[13] Some are prepared,[14] others are in the process of being written, and still others — for example, rules relating to facilities for permanent spent fuel storage — cannot be developed until the appropriate technology is established. We support this undertaking. To the extent that knowledge and experience permit, rules (and guidelines) made openly, and known by those who are affected, can enable the process of approval to proceed more efficiently and fairly.

In the United States, explicit and detailed design standards are specified by the regulatory agencies. By contrast, Canadian regulators have not attempted to specify design but instead have set radiation exposure and other standards as design objectives. For example, regulations under the Atomic Energy Control Act specify the maximum permissible radiation exposures for atomic radiation workers and for the general population. The industry establishes its design criteria to meet these objectives. Despite criticisms that the proponent may consequently be able to manipulate the regulator, we believe that this approach is appropriate because it makes the proponent clearly accountable for design decisions.

The standards are updated as new and better approaches are found for meeting safety requirements. To this end, the AECB participates with international agencies in research on areas of mutual concern. For example, regulatory bodies throughout the world are sharing information on emergency core cooling systems in order to improve the safety of nuclear reactors. Since current research may also lead to the necessity of upgrading existing installations, the AECB is involved in international investigations on retrofitting facilities. Similarly, co-operative research on an international scale is under way to develop universally applicable siting criteria.

Some of the rules concerning the design of facilities are regulations, requiring the approval of the Governor General in Council, and generally having the same effect as legislation, and others are merely informal guidelines. The choice between these forms has implications for controlling compliance and, more important, for the scope of hearings for approval of individual facilities. Whichever form is used, the role of the advisory committees has been important, and we have already commented on the desirability of their continued and expanded involvement. Other interested groups and individuals have had no right to participate, and we have concluded that rights should be given. However, we do not wish to suggest traditional adjudicative hearings for all rules. Procedures must be appropriate for the kind of

decision being made, and might range from an adjudicative hearing to an opportunity to make written comments. We approve the minimum requirement in Bill C-14: "a reasonable opportunity . . . to make recommendations" about proposed regulations. The procedures for participation in making guidelines can be more informal and should be left to the discretion of the AECB. These issues relating to the form of rules, and the rights to participate in making them, are general issues that we will consider at length in our final report.

Licensing

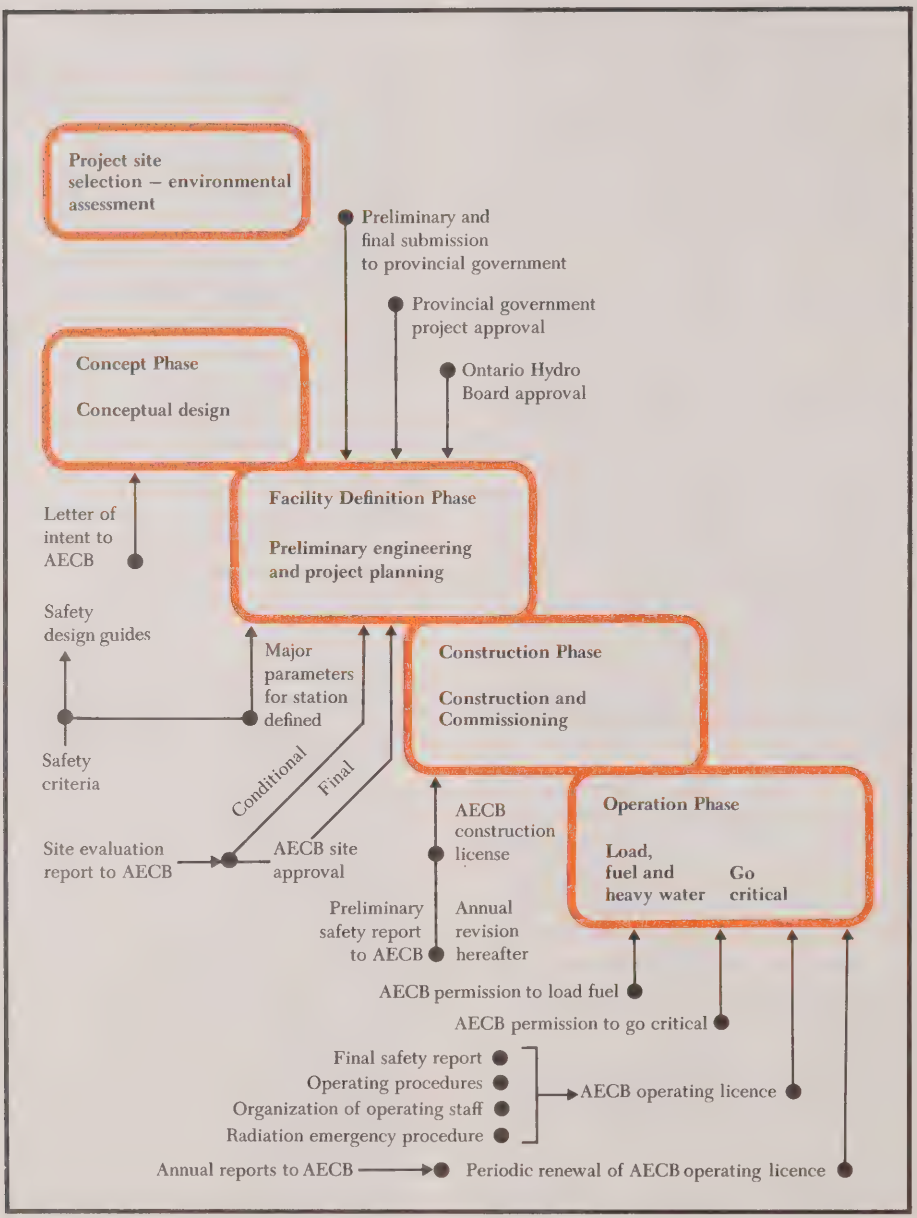
Another important and visible function of the AECB is the consideration of applications for licences to construct and operate nuclear facilities. Both the AECB and the provincial bodies place considerable emphasis on licensing because it is easier, and less costly, to require and to include protective systems when a facility is initially being constructed than it is to retrofit the facility at a later date. Licensing is a lengthy procedure, involving ongoing consultation between the Board and the applicant. It usually has three stages: site approval, construction licence, and operating licence (see Figure 12-1). At each step, the Reactor Safety Advisory Committee and the appropriate Board staff review the reports required from the applicant and make a recommendation.

We mentioned previously that none of the regulatory bodies has specified the actual design required for approval. However, the AECB must examine critically almost every decision made by the designers of nuclear reactors and other nuclear facilities. To test the safety of design features under extreme conditions, for example, the Board has required the applicant to calculate the effect of postulated accident situations, and to prove that the nuclear installation would not be unsafe under such conditions. The burden of proof is placed on the proponent. We encourage the continuation of this practice.

In the past, interested individuals and groups have had no right to participate in the licensing process. We have concluded, however, that such a right to participate should be given. Bill C-14 requires, as a minimum, a "public hearing" concerning applications for licences to construct nuclear facilities (except for some very small facilities). We approve this requirement. The construction stage appears to be the appropriate stage for a hearing, because the operation stage comes too late to permit an effective hearing, unless some sudden change in technology occurs. The recent experience in the United States suggests that unless care is taken in the timing, the scope, and the procedures for licensing hearings, they may become lengthy, frustrating and bitter. We suggest that they be held early enough to permit meaningful public input and to avoid any appearance that the outcome has already been determined by negotiations among the applicant, the Board staff and the advisory committees. The scope of the hearing must be limited to the appropriate concerns of the AECB: to protect health, safety and the environment from the risks associated with the use of nuclear power. In particular, the hearings should not consider general energy policy, economic and social choices, or the need for the individual facility or nuclear power generally.[15] These matters should be the responsibility of the Government of Ontario — in some instances (e.g. need) public hearings will be held. The procedures must give interested groups and individuals a reasonable opportunity to test the application and to submit evidence, opinions and argument. These issues of the appropriateness of hearings and procedures are general issues, which we will consider at length in our final report. However, one particular issue needs comment. During the licensing process debate may turn to design standards that regulate the facility under consideration. In our opinion the right to participate must permit adequate opportunity for discussion of these subjects, but at the same time must avoid substantial duplication with the procedures earlier discussed under standards setting.

The federal licensing process must be carefully co-ordinated with the provincial approval process, to avoid delay, confusion, and duplication of the efforts of the applicant. In both the federal and provincial processes site approval requires special attention, and possibly joint hearings would be useful. In general, we suggest as much use as possible of common documents.

Figure 12.1 AECB Process for Approving a Nuclear Facility



Compliance

The compliance function of the AECB is intended to ensure that nuclear facilities are operating and maintained in accordance with the conditions of the operating licence and the technical and administrative documents to which the licence refers. Reports on the facilities are submitted to the Board quarterly by AECB staff and annually by the licensee. Operating licences for nuclear facilities are not licences in perpetuity; rather, the Board issues licences for periods of one, two or five years (see Annex G). Licence renewal provides an opportunity for regular review by the Board staff, the Reactor Safety Advisory Committee, and the Board itself.

Since its inception, the AECB has followed a philosophy of constant on-site inspection and monitoring of nuclear facilities by a resident inspector. The on-site inspector is supported by the Reactor Safety Advisory Committee and the head office staff of the Board who, at appropriate intervals, tour the facilities, meet with the operators, and discuss safety-related issues. The identification of safety problems in one plant can lead to further investigation of similar problems which might arise in other plants. It was this type of review that uncovered the difficulties with the present emergency core cooling system in CANDU reactors. The Board took immediate action to find corrective measures that would allow safe ongoing production of electric power.

The use of resident inspectors has considerable merit and should be continued in every portion of the fuel cycle. But while we endorse the concept of resident inspectors, two issues require comment. First, the resident inspectors must not only be independent, but must also be seen to be independent. Small problems can be dealt with promptly by the resident inspector. However, a significant change often requires considerable negotiation. Because it may appear that the inspector "has to bargain" with the licensee to bring about alterations, it would be desirable if the regular reports filed by the inspector were made public.

Secondly, it might be desirable to provide a broader range of regulatory tools to the resident inspector. Re-licensing is one opportunity for ensuring compliance by a licensee. However, the time interval between licence reviews may be too lengthy for timely action. More frequent review might be helpful. For some non-compliance matters, the cancelling of a licence or refusing to re-license under full power may be too severe a penalty. A more appropriate approach might be to give powers, similar to those administered by the Ontario Ministry of the Environment, to order different degrees of penalties, which can be associated with different infringements. In other words, Ontario Hydro could be ordered to carry out corrective actions. Because these orders are public documents, the public can at the same time be reassured that the regulatory authority is carrying out its function and made aware of difficulties with particular components and operations of the nuclear fuel cycle.

Public Liability

As discussed in Chapter 6, an accident causing an uncontrolled release of radioactivity is extremely unlikely. However, as dealt with also in the same chapter, if one does occur, it will cause extensive personal injuries and damage to property. Legislation regarding public liability has been enacted in most countries that have nuclear power facilities. For example, in the United States, the Price-Anderson Act was enacted in 1957, and liability legislation was drafted in many European countries following discussions in the early 1960s. In Canada, the Nuclear Liability Act was enacted in 1970 and proclaimed in 1976. The AECB has a limited role to designate nuclear installations and to prescribe the basic insurance requirements for such installations. Through the Nuclear Energy Agency of the OECD, Canada is participating in a major re-evaluation of the maximum amount of liability, the substances that are subject to liability coverage, and the definition of "nuclear installations" in this kind of legislation.

The Nuclear Liability Act is divided into two major parts. Part I imposes liability on "an operator", regardless of fault, for all personal injury and damage to property that is "occasioned as the result of the fissionable or radioactive properties . . ." of nuclear material in a nuclear facility or in transit to or from the facility. The operator must obtain at least $75,000,000 of insurance against this liability.

However, if the total liability from an accident seems likely to exceed $75,000,000 or if "it is in the public interest to provide special measures for compensation", the federal government must make a declaration that the liability falls under Part II of the Act. A specialized tribunal, the Nuclear Damage Claims Commission, must be established, to hear claims for compensation. The liability of the "operator" to the public would be terminated, but it must pay the government $75,000,000. The Nuclear Damage Claims Commission would not pay compensation. Instead it would make orders for compensation, which the Minister responsible for enforcing the Act may pay, but no more than $75,000,000 may be paid without the approval of Parliament. The government may make regulations about limits on awards, priorities among claimants, means of payment, requirements for proof of claims, and time limits.

We approve the general objectives of the Nuclear Liability Act. The basic principle is that anyone who suffers loss from a nuclear accident should be paid reasonable compensation regardless of fault. If the losses are confined to a few individuals or a small area, the compensation should be paid by Ontario Hydro. The claims should be made in the courts, and governed by the general rules covering these kinds of losses and measure of damages, although minor changes about causation and time limits may be useful. But if the losses are immense and widespread, compensation should be paid by government. The claims should be administered by the Nuclear Damage Claims Commission, and some limits may have to be imposed on the kinds of losses for which compensation is made. This limitation of the liability of the utility is really a form of subsidy as we pointed out in Chapter 7.

The Act does not impose an obligation to pay this compensation under Part II. This lack of precise obligation is unavoidable, because of the possible need to make appropriate arrangements and limits that cannot now be foreseen, but the basic principle remains: the government should pay reasonable compensation. Whether the provincial government or the federal government or both should pay this compensation is a difficult issue. The particular facility associated with an accident is, in the case of Ontario, owned and operated by the provincial utility for the benefit of the residents of the province, but the federal government has a large role in and commitment to the general nuclear programme of the nation. Clearly, sharing of such costs should be considered.

If a massive disaster occurs, a wide range of other government responses — for example, the provision of medical treatment, food, and shelter and community relocation — would be necessary. Although these needs are difficult to predict, responsibility and authority for making responses should be established.

Decisions on "Need for Nuclear Power"

As we mentioned at the outset of this chapter, the question of the "need" for nuclear power is one which the public has increasingly brought before regulatory bodies. Many intervenors argue that hearings on health, environment and safety are unnecessary, because nuclear power itself is unnecessary. Much of their argument centres on the relationship between economic growth and energy supply, future lifestyles, the social effects of centralized energy technologies and the allocation of capital resources among competing energy alternatives. This argument has been put forth by both the supporters of a renewable energy future and those who advocate an acceleration of high technology.[16] From our perspective the issue is not whether the question of need should be debated but rather where and when it should take place.

In our view an expanded nuclear power programme should be considered as a component — but only one of many — of a broader energy policy for the province. So that nuclear power can be analyzed as part of an overall energy strategy, we believe that a holistic evaluation of generation options should be made on a regular basis. Total fuel cycles should be considered in terms of comparative risks, employment and industrial strategies, social and environmental effects, and intergovernmental relations. We believe that the rationale for a nuclear project should be open to public scrutiny. In our view the Ontario Environmental Assessment Act provides the appropriate basis for public review of the comparative social and environmental implications of a nuclear power development.

However, even if the province provides fair

and adequate scrutiny of need, some intervenors have suggested that the federal Board should itself judge the need for and appropriateness of nuclear technology to meet future energy requirements. The AECB, on the other hand, has been very firm in its conviction that the decision on the kind of technology used to generate electricity is a matter to be resolved at the provincial level. We concur with this position. The federal agency should concentrate on the important specific matters relating to safety, security, health and environment.

Regulation and the Nuclear Debate

The complexity of the technology and the deep polarization of opinion both on the broader aspects of technology choice and the more specific questions of risk and benefit, complicate decisions about nuclear power. Such decisions are "political" in the broad sense of the word because they involve choice among competing interests and value systems and a consequent allocation of costs, risks and benefits. Government is deeply involved in all aspects: the executive and legislative levels that make the broad policy decisions; the regulatory agencies that have decision-making authority, or advisory roles, in areas requiring specialized knowledge; corporations that administer the policy decisions.

This chapter has focussed on a narrow portion of this spectrum, concentrating primarily on the mechanisms of regulation and review of the health, safety and environmental impacts of the nuclear initiatives of Ontario Hydro and other public corporations. We have not, for example, discussed the important topic of regulatory streamlining.[17] We acknowledge, however, that public confidence in regulatory decisions depends also on a perception of the need for nuclear power within a particular time perspective. The choice or rejection of nuclear power in Ontario is part of provincial energy policy involving a comparison of the total impact of energy technologies, including conservation. Such an evaluation also affects employment and industrial strategy and social and environmental policy. Although the question of need should be publicly debated, much of the debate should take place through the political process rather than at regulatory hearings. But decisions about nuclear power will be acceptable only if made through an open process by those who are fully accountable for their decisions. Part of the challenge of institutional and procedural design is to ensure an appropriate allocation of responsibility for decisions among the different types of "government" and an acceptable process of decision-making. We will examine this topic in detail in further hearings.

Chapter Thirteen

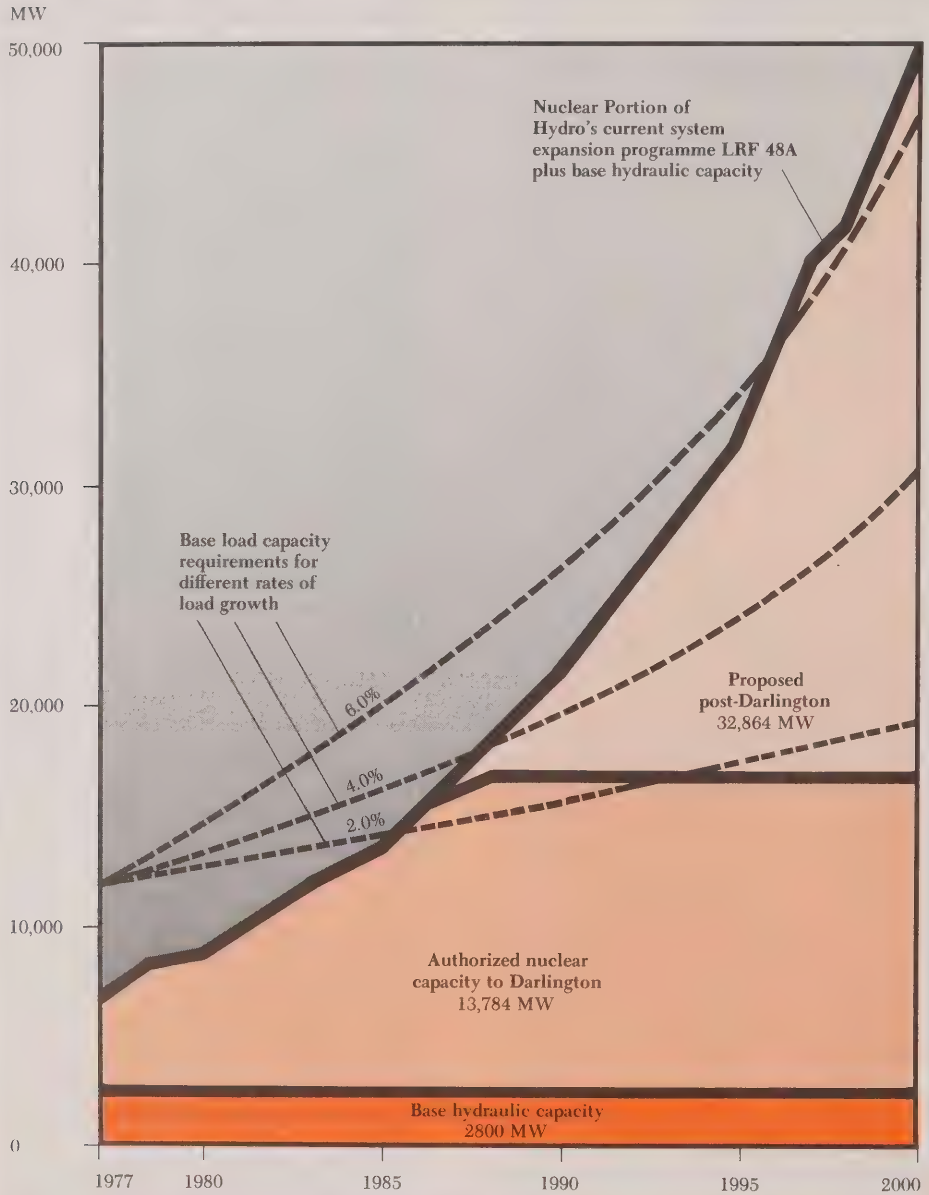
The Hard Decisions Ahead

THERE is no reason to believe that the major physical, social, economic and psychological adjustments to new energy sources and policies will be easy, especially in view of the increasing complexity and inbuilt inertia of modern society. The conditions during the period 1983-93 and beyond will necessitate an expanding search for innovative and more sustainable sources of energy, a more efficient, elegant and wise use of energy and most importantly, the realization that our energy balance may depend on a remoulding and reshaping of our institutions, organizations and value systems. Diversity, flexibility and resiliency should characterize our energy supply systems. Renewable and non-renewable, centralized, and decentralized systems should be deployed. We believe that there should be increasing efforts to match, most appropriately, energy quality with end-use requirements. Institutional barriers, other than ecological controls, should be removed to allow for full development of all technologies which are appropriate to Ontario's resources and needs. Above all, government, energy corporations and citizens must co-operate in the development of an energy system which is both responsive to changing societal needs and equitable in the allocation of costs and benefits.

It is highly probable that before the turn of the century we will begin to experience shortfalls in oil supplies. The challenge we face is to minimize the social consequences by striving to ensure that, at worst, inconvenience rather than trauma results. Our strategy should seek to create an orderly, sustainable energy supply while reducing exponential growth in energy demand without restraining economic growth. Substitution for depleting oil resources must come from a range of options including conservation, renewable energy systems, coal and electricity. There will have to be an intensification of research and development programmes as well as demonstration and commercialization of substitutes for the conventional energy sources. The objectives should be to stretch existing fuel supplies and to utilize indigenous energy sources to the greatest extent possible. A goal of provincial energy self-sufficiency is in our view not achievable. Inevitably we believe we will have to develop with our neighbours a more integrated energy strategy. A necessary starting point is the continuing development of a comprehensive provincial energy policy which is open to public discussion.[1] However, ultimately we must face the necessity of co-operating in the development of not only a national but, perhaps, a continental energy policy. Although the question of "electric power interconnections" remains to be debated, there is obviously scope for innovation. One need look no further than the continental telephone system to recognize the benefits to be derived from rationalizing service, equipment and capital. It is our present belief that a continental interconnected electricity system would allow for a similar optimization, for the maximum use of renewable electrical generation systems, and for the minimization of the need for new generating capacity. A continuous upgrading of existing interconnections is clearly desirable.

In our search for rapid development of energy supply substitutes we must always be aware of the risks and costs to man and his environment. We must not become so short-sighted that we destroy our food lands, mismanage our forests, or pollute

Figure 13.1 Ontario Hydro's East System Base Load Capacity Requirements to 2000 For Different Rates of Peak Load Growth



our watercourses, and therefore, leave a legacy of environmental degradation to our future generations. Clearly no single energy technology has a monopoly on the solution to these problems. In this report, for example, we have dealt extensively with the environmental problems associated with the nuclear fuel cycle. But for technologies such as the transportation of liquefied fuels (e.g., propane and liquefied natural gas), the production of chemicals and pesticides, and the refining and smelting of metals also give rise to formidable insults to the environment. Although participants in our hearings displayed polarity in their views, particularly on the issue of nuclear power, we noted a high level of agreement on fundamental issues of society, including: the protection of the ecosystem, the preservation of agricultural lands, the maintenance of living standards and the wise use of non-renewable resources.

Society's perceptions of the need for nuclear power depend to a large extent on its perceptions of the future demand for electricity. In Chapter 2, we presented three scenarios — "high" (6 per cent), "medium" (4 per cent), and "low" (2 per cent) annual growth in demand for electrical energy in Ontario for the period 1975 to 2000. We believe all are credible but the medium growth rate is most probable. The degree to which electricity use will in fact increase will depend not only on future economic and population growth but in addition, on the extent to which coal, renewable technologies and conservation will substitute for dwindling oil resources. It will also depend on the degree to which government is willing to manage demand - truly a hard decision. For an energy-importing province like Ontario, such intervention in individual and corporate energy decisions should not be unthinkable. On a national basis we are already beginning to see such intervention through automobile mileage regulation, appliance efficiency standards and even preparations for oil rationing. We encourage the Government of Ontario to add strength to these initiatives by adopting a more visible role in managing the demand for all forms of energy.

Our analysis of the foregoing has led us to the conclusion that we are in a race against time, a race that will necessitate prompt action and many hard decisions. It is against this backdrop that we will discuss our interim conclusions on the proportion of nuclear power, future research needs, the appropriate allocation of capital and the role of the public in decision-making.

Our analysis of the future growth in demand for electric power has led us to the conclusion that if Ontario Hydro is to service the additional load with a reasonable level of reliability, then some expansion of the bulk electrical supply system before the year 2000 is inevitable. Our three scenarios for average growth rates for electricity in the East System to the year 2000 reveal the following:

Growth rate	Peak demand	Increase in peak demand since 1977
	MW	
2%	23,420	8,570
4%	36,610	21,760
6%	56,740	41,890

In the Table we have not included a consideration of Ontario Hydro's West System. The West System is quite small with a December 1977 peak demand of 845 MW as compared to 14,854 MW for the East System. Ontario Hydro is currently adding two 200 MW coal units to the West System which will come into service in 1983. For system reliability reasons units larger than 200 MW would not be advisable on the West System. We therefore have concluded that, considering the economics of 200 MW nuclear units, we believe that during the period up to the year 2000, firm contracts to purchase base load hydraulic power from Manitoba Hydro or the development of biomass systems may be superior options. We will discuss this further in our hearings on The Total Electric Power System. We would encourage the strengthening of the interconnection with Manitoba.

Following the principle for base load generation which we outlined in Chapter 3, the required installed base load capacity of the East System in the year 2000 under the same three scenarios would be low — 19,400 MW; medium — 30,400 MW; high — 47,100 MW, as shown in Figure 13-1.

In their submission "The Generation Planning Process" Ontario Hydro indicated that their present planning objective is to meet all base load gen-

eration requirements with a combination of hydraulic and nuclear capacity. Upon the completion of the Darlington Generating Station in 1988, the utility will have an installed base load capacity of approximately 2800 MW of hydraulic generation and approximately 13,800 MW of nuclear generation for a total of about 16,600 MW. The post-Darlington, additional base load capacity needed by the year 2000 would be as follows:

Load growth	Total Base load capacity required to 2000	Post-Darlington additional base load requirements to 2000
	MW	*MW*
2%	19,400	2,800
4%	30,400	13,800
6%	47,100	30,500

This additional base load capacity could be met by any one of three options: all nuclear, all coal, or a combination of a small amount of hydraulic, some biomass, some coal and some nuclear. Although our interim conclusions lean strongly toward the third option, it is convenient to consider the implications if the *total* base load requirement were met with nuclear power. The needed base load capacity under the 2 per cent growth rate scenario could be met by one additional station of the Darlington size (3400 MW) while the base load requirements for the 4 per cent and 6 per cent growth rate scenarios would require respectively four and nine Darlington-size additional stations. The requirements for capital, heavy water, and uranium are indicated in the table below.

On December 31, 1977, Ontario Hydro had 3800 MW of nuclear power installed. Even assuming a capacity factor of 70 per cent (the actual value was over 90 per cent in 1977),[3] nuclear power was capable of supplying 27 per cent of total electrical energy generated in the province during 1977. With the completion of the Darlington G.S., the nuclear programme operating at a lifetime expected average capacity factor of 70 per cent will be capable of supplying 63 per cent of total electrical energy, assuming a 4 per cent load growth. Under the three scenarios, nuclear power, if fully deployed in the year 2000 to fill the additional base load requirements, would supply the following percentages of total electrical energy:

Growth rate	Nuclear as a percentage of total electrical energy
	(at 70% capacity factor)
2%	75%
4%	79%
6%	82%

The addition of approximately 3400 MW of nuclear capacity under the 2 per cent growth scenario would face no major constraints. Capital could readily be raised. Sufficient fuel would be available since the amount required is less than the excess in the combined Denison and Preston contracts. The station could be located on an existing generation site. The health, environment and safety problems would not be appreciably more difficult to manage than at present provided that satisfactory progress is made in the demonstration of acceptable waste disposal techniques. The scenario might, however, present difficulties for nuclear component suppliers who would face a limited domestic market for their products. Since the installed capacity would not be required until the period 1992-2001 the availability of indigenous suppliers at that time may be contingent upon sufficient numbers of CANDU sales outside of Ontario. These sales would be largely beyond the con-

Load Growth	Nuclear Capacity Addition	Capital	Heavy Water	30 year Uranium Suppl
	(MW)	*($2000/kW)* *Current $**	*tonnes*	*tonnes*
2%	3,400	6.8 billion	3,100	14,400
4%	13,600	27.2 billion	12,500	57,500
6%	30,600	61.2 billion	27,500	129,500

*This is an approximated figure for capital costs on an installed kW basis averaged over the period 1975-2000 in current dollars.[2]

trol of the Government of Ontario. Assuming that at least one domestic supplier will be available for the major components, we anticipate that Ontario Hydro should expect to pay at least a 10 per cent premium on the price of CANDU components.

The addition of four stations (i.e., 13,600 MW) under the 4 per cent growth scenario could probably be financed without jeopardizing the provincial credit rating provided there were appropriate increases in electricity rates. As to fuel, approximately five reactors of the 850 MW size could be fuelled for their lifetime based on the surplus in the existing long term uranium contracts. However, in addition to this uranium, approximately 40,000 tonnes would have to be acquired to ensure that the reactors could operate on a once-through cycle. We are of the opinion that Ontario Hydro could probably secure this additional fuel, although perhaps on terms less favourable than the recent contract and probably not within Ontario. The level of orders to the component industry that would result from four additional stations would probably be sufficient to ensure the availability of at least one supplier for each major component. Siting of these stations could be partially accommodated on existing sites although it is expected that the utility would have to acquire one additional dedicated site for a programme of this size.

The status of the waste management programme in the early 1980s could prove to be a major constraint to the addition of 13,600 MW of nuclear power. Significant advances would have to be demonstrated before a programme of this size should be endorsed by government. We are also concerned about the resiliency and vulnerability of a system that would use such a large portion of nuclear power to supply the province's electric power and energy requirements. A major accident or terrorist incident at an Ontario Hydro nuclear station, or indeed at any nuclear station in the world, could result in at least a temporary shutdown of all of Ontario's nuclear capacity. In our opinion, the addition of four nuclear stations after Darlington G.S. would not provide the flexibility that is desirable in the system. Therefore, we have concluded that the *maximum* number of additional nuclear stations should not exceed three, that reactor size should be standardized at 850 MW and that one additional site should be dedicated to this nuclear programme. We have also concluded that the heavy water output from the third plant at the Bruce complex is unnecessary for the Ontario programme.

We do not endorse a nuclear programme which would add nine additional stations for the reasons mentioned previously. Furthermore, there are two additional concerns which relate to capital requirements and advanced fuel cycles. The availability of capital thirty years hence is a highly speculative matter. We have noted that experts in the Ministry of Treasury, Economics and Intergovernmental Affairs tend to have more pessimistic views on this long term question than do Ontario Hydro's analysts. We believe capital requirements for such a major nuclear programme would strain the upper limits of public capital availability. Large rate increases would probably be required. We have also concluded that the availability of indigenous uranium and associated production capacity presents serious potential constraints; these are only partially amenable to action by the Government of Ontario. The uranium required would be more than one and a half times greater than the amount secured under the long term contracts with Denison and Preston. In all probability, a programme of this size would require the introduction of advanced CANDU fuel cycles, an initiative which the Commission does not endorse at this time.

The question of how best to supply the additional base load requirement beyond that which three nuclear stations would provide is one of the hard decisions that must be addressed. Hydraulic systems will be capable of supplying only a small portion of the additional requirement. A major coal station could provide a significant portion of the 3400 MW shortfall in required capacity under the 4 per cent growth scenario, but the Commission believes that a mixed programme of hydraulic, coal and biomass would be more appropriate. A minimum of 1500 MW of the 3400 MW requirement should be supplied by biomass generation developed on an energy forest concept.

Properly managed, a woodland plantation can produce thermal energy at an equivalent rate of about 5 tonnes of coal per hectare per year. Furthermore, it is perpetual energy, indigenous to

Ontario, which may be in the form of wood chips and/or, eventually, liquid fuels. Herein lies a major challenge for Ontario.[4] Based on a major study undertaken on behalf of the Commission by Dr. Morris Wayman and Jairo H. Lora, research on hybrid poplar by the Ministry of Natural Resources, and encouraging discussions with Dr. J. Hodgins of Domtar Inc., who are developing plantation forests, we are of the opinion that the wood-fuelled electric power capacity in Eastern Ontario by the year 2000 should be at least 1500 MW. The associated power plant or plants could be large or small. Furthermore, these plants could be conventional or based on modern gas turbine technology. Such schemes would have the following significant advantages:

- The environmental impacts related to the use of wood fuel are minimal. Indeed, some of them are positive; for example, the absorption of carbon dioxide and the generation of oxygen; the use of wood ash as fertilizer (only nitrogen would need to be added); and the creation of recreational terrain.
- Abandoned farmland, as well as marginal quality lands, could be utilized productively.
- The employment-creating potential is appreciable.
- The province's educational base in forestry is renowned, and could provide the personnel base for a new industry.
- The Ministry of Natural Resources is already active in the development of fast growing trees, notably hybrid poplars, and is pioneering much of the development and demonstration of the concept.
- Advanced technologies for processing the "whole tree" are now available and further advances are being made.
- The prospects for co-operative programmes with other provinces, especially Quebec, are considerable. So too is the export potential of this new technology.

Ontario Hydro took a bold leap forward when they participated with AECL in the development and demonstration of the CANDU reactor. We believe the utility will rise to yet another challenge by participating in a major development and demonstration programme of electricity generation based on the energy forest concept.

Critical to the development of a flexible energy future is a careful focussing and allocation of Ontario's capital resources to both social development and research. Unquestionably, there is a need for imagination and innovation, not only in applied science and technology, but also in our social and institutional structures.

Currently, 80 per cent of Ontario's population lives in urban centres and this percentage is increasing. Our energy problems are in many ways the problems of urbanization. The urban centres look to the rural hinterland for their voracious energy and resource needs. This is rapidly resulting not only in environmental degradation and the disappearance of agricultural land but in an uneven and perhaps unjust distribution of risks and benefits. These developments will increasingly be expressed in political confrontation as minority segments of society express their desire to maintain a particular lifestyle.

Governments must gain control over the burgeoning energy requirements of the cities. Capital must be redirected to allow for energy efficient city and town planning and for the retrofitting of existing structures. The practice of energy conservation in its most basic sense should underpin the planning process. In the short term, large capital expenditures may be needed to achieve energy efficiency in the long term. Among the ideas which we believe deserve very serious assessment:

- district heating based on high-efficiency cogeneration plants;
- total energy management systems for large apartment, shopping and office complexes which capitalize on renewable resources and on the efficient utilization of primary fuels;
- an efficient transportation system based essentially on electric traction — small electric cars, electric buses and electrified railroads for rapid intercity transportation;
- the development of new building codes and standards incorporating the conservation ethic in the sense of utilizing, for example, passive solar space and water heating; and
- capitalization based on the principle of trading off energy-intensive transportation of people against energy-efficient electronic communications wherever possible (e.g., two-way cable tele-

vision systems).

Our industrial structure could also benefit from greater energy efficiency. Expenditures in the order of $1.75 billion could make a major Ontario industry, pulp and paper, virtually self-sufficient in energy and certainly more competitive on a world scale. Domtar Inc. is already saving 400,000 barrels of oil a year by utilizing a new bark-burning boiler at their mill at Lebel-sur-Quévillon, Quebec. Many industries could utilize efficient co-generation systems and thus minimize their dependence on the electric power grid. These and other imaginative schemes, such as energy storage techniques, will require a major redirection of capital if they are ever to be implemented. We believe that through effective intermediation, capital which would normally be expended on bulk supply systems could be effectively utilized in measures to reduce demand and to bring about greater overall energy efficiency without significantly altering our lifestyles. Indeed lifestyles might be improved.

However, irrespective of the measures to control the growth in demand, we see the need for significant expenditures on supply technologies if we are to have a range of energy options by the year 2000. Nuclear power is in our view one of the options which should be available at the turn of the century. For it to be an acceptable option to society, carefully directed expenditures must be made on exploration, research and development. Additional uranium supplies will have to be found, mined and milled. This will not only be expensive but will result in additional and very large quantities of wastes from the uranium mining and milling process. Governments must work closely with the uranium industry to ensure that satisfactory containment of these radioactive wastes for very long periods of time is carried out. If governments want the benefits of nuclear power, then they must assume some of the responsibility to minimize the risks which arise in all components of the nuclear fuel cycle. The urgency of moving ahead on a long term programme for the management of spent fuel cannot be overstated. The future of a nuclear programme will be highly dependent on finding and demonstrating a socially and technically acceptable solution to this complex problem. The industry, of necessity, will have to work more closely in an open and informative manner with the communities most directly impacted by a waste demonstration programme. However, although much of the public focus has been on the nuclear waste problem, we believe this need should not overshadow the requirement for continued research on nuclear safety. Nuclear power will only be a viable option as long as it is perceived as a safe technology.

In our opinion, reprocessing is not an area which should receive extensive research support at this time. We do, however, believe Canada should explore opportunitites to enter into a joint research programme with the United States on advanced CANDU-thorium cycles in order to optimize both Canadian and United States resources. This fuel cycle could be of significant benefit to Canada's energy requirements in the 21st century and could complement possible American advanced fuel cycle programmes.

Nuclear power should not continue to receive the dominant portion of energy research and development funds. To ensure flexibility in our energy options by the year 2000, we encourage much greater expenditures in the renewable technologies. For Ontario particularly, these expenditures should in our view be directed to technologies which exploit indigenous resources and are compatible with our region. Biomass systems, based on energy forests, deserve much greater attention, as do energy storage schemes and appropriate solar developments. Our expectations for these technologies before the year 2000 should not be exaggerated, but we believe the technologies should be developed now if benefit from them is to be derived in the latter part of this century and indeed into the future.

The internationally recognized research capability of AECL could be of substantial assistance in the development of renewable energy technologies. It is our belief that significant benefits would accrue to the people of Canada and Ontario if the nuclear research laboratories of AECL were converted to a National Energy Laboratory.

Coal will also have to play a more significant role in our future energy mix. The quantities required by a large Ontario Hydro coal generation programme could justify major capital expendi-

ture on a slurry pipeline from western Canada. Ontario Hydro's initiative in this area could provide both a flexible and secure fuel supply to the utility as well as offering significant benefits to Ontario industries which could base their process heat requirements on reliable supplies of coal.

The fundamental decisions about nuclear power are all political. They have to do with quality of life, with quality of the environment and with the energy options we want to leave to our future generations. These are hard decisions which ultimately must be made by government. But government requires the benefit of the public's views on these far-reaching public policy issues. New and imaginative forums must be found to involve the public, who's input must be sought at every step of the fuel cycle. Education and information will be essential.

The government and the public can no longer sit back and be relatively uninterested in the generation decisions made by the utility. We must become knowledgeable about the proposed technologies, their environmental, societal and political implications, and their capital and fuel requirements both in the short and long term. We must all enter the debate in a process designed to give political direction to the utility.

The range and polarity of views about nuclear power indicate some deeply felt concerns that in all likelihood will lead to a prolonged and ongoing debate. But we believe that an informed public debate might make the achievement of a just and wise consensus possible. Perhaps our Commission is the beginning of a process of education and discussion which will allow society to form and to shape a mature and sophisticated understanding of nuclear power and thereby give an informed input to the decision makers. We believe that armed with such public understanding, we might move more quickly to rational and sustainable solutions to the energy planning problem.

Notes to Chapters

Notes to Foreword

1. Ontario Hydro, established in 1906, is Canada's largest electric utility. Dependable peak capacity was over 21,000 MW in 1977. The publicly-owned utility operates two essentially independent systems in the east and west of Ontario and provides about 95 per cent of Ontario's electrical requirements. Ontario Hydro serves 340 municipal utilities, 100 large directly served industries, and 800,000 rural retail customers.

2. Royal Commission on Electric Power Planning, *Our Energy Options* (Toronto, 1978). This series of essays, financed by Richard Ivey Foundation, includes Walter Murgatroyd, "Efficient Utilization of Energy"; Donald N. Dewees, "Environmental and Health Issues of Power Generation"; Robert K. Swartmen, "Alternate Power Generation Technologies"; Robert E. Jarvis and John S. Hewitt, "Nuclear Energy in Our Time"; Leonard Berton,"Fuels for Power Generation"; O.M. Solandt, "Bulk Transmission of Electric Power"; and Clifford Alan Hooker, "The Socio-economic Significance of Electric Power Policy".

Notes to Chapter One

1. "Energy and Development", *Science*, Vol. 200, No. 4338, April 14, 1978.

2. See Chapter 3. The radioactive isotopes, fissionable by thermal neutrons, are uranium-233, uranium-235 and plutonoium-239. These are the materials from which nuclear weapons can be made — a "critical mass and appropriate geometrical configuration" of each of them will, when triggered, explode spontaneously. From the standpoint of civilian nuclear power, uranium-235 is the most important fissionable isotope because it is the only one which occurs naturally in adequate quantities. All nuclear reactors are based initially on uranium-235. Subsequently the isotopes uranium-233 and plutonium-239 may be obtained from reactors in which thorium-232 and uranium-238, respectively, are present as the "fertile isotopes" (the term "fertile" is used because fissionable isotopes can be "bred" from them).

3. Report of Conference on "Environment and Society in Transition: World Priorities", in *Annals of the New York Academy of Sciences*, Vol. 261, 1975, p. 216.

4. Sir Peter Masefield, "Towards Tomorrow: Changes and Challenges", *Journal of the Royal Society of Arts*, Vol. CXXVI, No. 5257, December 1977, p. 11.

5. "Report on Nuclear Energy", "Anticipation" in the Journal of the World Council of Churches, No. 21, October 1975, p. 15.

6. Even such sensitive topics as how to make a nuclear bomb are not excluded. Fortunately, information on how to obtain the fissionable material needed to make a nuclear bomb is not included in the literature. For a detailed discussion of the subject see A.B. Lovins, *Soft Energy Paths: Toward a Durable Peace*, Cambridge, Mass.: Ballinger, 1977.

7. It is important to note, in this respect, that peer review of papers in the field of nuclear science and engineering is one of the most effective means of ensuring high safety levels of nuclear reactors, as well as facilitating the search for safe methods for the disposal of highly radioactive materials (such as spent nuclear fuels).

8. In the annotated bibliography, we draw special attention to: Nuclear Energy Policy Study Group, *Nuclear Power: Issues and Choices*, Cambridge, Mass: Ballinger, 1977; and Royal Commission on Environmental Pollution, *Sixth Report: Nuclear Power and the Environment*, London: H.M.S.O., 1976.

Notes to Chapter Two

1. It is important to distinguish between the demand for electric power (measured in kilowatts or megawatts) and the demand for electric energy (measured in kilowatt-hours, etc.). The former relates to the capability of the power system to meet all system demands at every instant of time (especially the demand during the "coldest hour" in January). The latter relates to the amount of electricity we use on a day-to-day or a year-to-year basis. Electric power capability depends solely on the availability and reliability of a complex system of generating stations, transmission lines, transforming and switching stations and distribution networks. On the other hand, electric energy is directly related to the amount of hydraulic power which is harnessed, to the amount of coal, oil, gas or uranium fuel consumed, and to the efficiency of the associated energy conversion processes.

2. This assumes a middle-of-the-road projection of growth in Canadian primary energy consumption of 2.8

per cent annually to 2000, and oil consumption increases of 1.1 per cent over the same period. This rate is governed by expected availability of Canadian oil and a federal government target that oil imports must not exceed 800,000 barrels a day, or one-third of total Canadian consumption, after 1985.

3. Although Canada had a favourable overall balance of energy trade of $900 million in 1977, net oil imports were $1.7 billion. Statistics Canada, *Exports by Commodities*, December 1977, Cat. No. 65-004 and *Imports by Commodities*, December 1977, Cat. No. 65-007 (courtesy Elizabeth Ruddick, Infometrical).

4. R.B. Toombs, "Canada's Energy Strategy", Notes for Energy Conference, London, University of Western Ontario, April 1, 1978.

5. We use the terms "growth", "growth rate", and "rate of growth" synonymously.

6. It is actually slightly greater than the sum of the population and per capita growth rates. However, for growth rates less than about 10 per cent per annum, this is a fairly accurate approximation. The exact formula is: $r_E = r_p + r_e + r_p \times r_e$ where r_E = energy growth rate, r_p = population growth rate, and r_e = growth rate of energy consumption per capita. The last term is small for low growth rates and is usually neglected.

7. Christopher E. Taylor, *Population Growth, Demographic Views, and Their Relationship to Electrical Energy Planning*, Report submitted to RCEPP, March 1978. Mr. Taylor's forecast is based essentially on the lower fertility assumption of the official forecast and substantially less immigration.

8. Clearly the desirability of decoupling economic activity and energy use was considered at the recent Bonn Economic Summit Conference (July 1978) where "President Carter also agreed to follow the European Community's example in limiting growth in energy demand to 80 per cent of G.N.P.", *Financial Post* July 22, 1978.

9. Possibly people are beginning to realize that conservation may be cheaper than adding to energy supplies. A number of studies have shown that a given investment in sensible energy conservation programmes makes more net energy available than a similar investment in developing new energy supplies because of the energy involved in producing and delivering energy. Up to a point, conservation can also provide a higher rate of return than other alternative investments available to the householder or businessman. See, for example, Denis Hayes, *Energy: The Case for Conservation*, Worldwatch Paper 4, Washington, 1976, and Science Council of Canada, *Canada as a Conserver Society*, Report 27, Ottawa, 1977.

10. See especially Lee Schipper and Joel Darmstadter, "The Logic of Energy Conservation", *Technology Review*, January 1978, p. 41.

11. For a more detailed description see Royal Commission on Electric Power Planning, Issue Paper No. 3, *Conventional and Alternate Generation Technology*, January 1977. See also Annex E.

12. U.S. National Research Council, Committee on Nuclear and Alternative Energy Systems (CONAES): *Interim Report*, Washington: National Academy of Sciences, 1977, p. 4.

13. End-use energy excludes energy used by the energy supply industries themselves, such as coal, oil and natural gas used for electric generation, as well as energy used in the extraction, processing and delivery of oil, gas and coal to final users.

14. Alvin Weinberg, Lee Schipper, and others recognize the virtues of "thermodynamic matching" but are critical of the almost religious significance attached to the concept by Amory Lovins and his supporters. It is, they say, too uni-dimensional, may involve much waste of other resources, and ignores important environmental and social factors. See, for example, Alvin Weinberg's review of Amory Lovins, *Soft Energy Paths*, in *Energy Policy*, March 1978.

15. At an energy seminar in Vancouver on February 23, 1978, the then Deputy Minister of Energy, Mines and Resources Canada said that renewable technologies "might" meet 6 per cent of Canadian primary energy demand by 1990, but that this would be equivalent to their providing one-half the heating load of the projected five million single-family dwellings in place that year.

16. Derived from Energy, Mines and Resources Canada, *An Energy Strategy for Canada*, Ottawa, 1976.

17. From the Minister's preamble to Energy, Mines and Resources Canada, *Energy Conservation in Canada*, Ottawa, 1977, p. 2, which set out a 2 per cent primary energy growth path (equivalent to a 1.3 per cent rate of growth of secondary or end-use energy). Our energy growth coefficient of 0.31 is the ratio of this 1.3 per cent to the 4.2 per cent economic growth assumed by EMR.

18. The model is formulated in end-use terms discussed in note 13. The corresponding energy growth coefficients tend to be lower than the more generally used values of the coefficient which are based on primary energy.

19. The energy "decoupling" implied in Figure 2-6, instead of continuing indefinitely, may last only over a period of, say, fifteen to thirty years during which Canadian energy efficiency may be brought closer to the

point allowed by thermodynamic limits. Ultimately, the energy growth/economic growth ratio will probably increase again, and the dominant question will then become the form economic growth assumes in a future, structurally different, "post-industrial" world.

20. Institute for Energy Analysis, *U.S. Energy and Economic Growth, 1975-2010*, Oak Ridge Associated Universities, September 1976.

21. E. Haites , *Projections of the Final Demand for Energy in Ontario to the Year 2000: Part Two*, Toronto: RCEPP, 1978.

22. E. Haites and J. Sullivan, *Projections of the Final Demand for Energy in Ontario to the Year 2000: Part One*, Toronto: RCEPP, 1978.

23. W. Murgatroyd, "Efficient Utilization of Energy", in *Our Energy Options*, Toronto: RCEPP, 1978.

Notes to Chapter Three

1. In comparing 1250 MW nuclear units with smaller plants, Ontario Hydro's preliminary assessment is that a penalty of 3 per cent of the net energy output for the mature 1250 MW station is required to compensate for the higher forced outage rate of the larger units. (Ontario Hydro, "Economic Evaluation of 4 × 850 versus 4 × 1250 MW Nuclear Plant", submission to RCEPP, Exhibit 328-21, p. 2.)

2. System reserves depend on both the incremental reserve requirements and the requirements dictated by past capacity. Ontario Hydro's preliminary analyses of system expansion options suggest that if nuclear and fossil units were added in the ratio of 2:1, system reserve margins, to maintain a loss of load probability of 1 in 2400, would be 24 per cent with 850 MW units and 27 per cent with 1250 MW units. These figures include the effect of low reserves required for existing hydraulic capacity. In an economic comparison of 1250 MW and 850 MW units, Ontario Hydro incorporated a penalty of 1 per cent of the net output of the 1250 MW units to reflect this factor. *Ibid.*, p. 3.

3. In the Interim Report of the Royal Commission on Development in Northern Ontario Mr. Justice Patrick Hartt did not pass judgement on the Onakawana project but stressed that local communities and affected groups should be fully consulted in the course of preparation by the mining company involved in any environmental assessment of the project.

4. These may not look much like plateaus on Figure 3-2, but compared with those of other electric utilities, Ontario Hydro's daily load factor is high and the load curve is correspondingly relatively flat.

5. The expansion programme reflects Ontario Hydro's best judgement of the appropriate balance between technical, economic, environmental and other factors. The programme is specified in a long range (twenty or thirty years) capacity forecast designated by LRF (long range forecast) and a number. Ontario Hydro has emphasized that LRFs are adopted by its Board as planning documents only and any estimates beyond committed projects should be used only as general indicators of the timing and magnitude of additions to generating capacity. Nevertheless, the LRFs adopted since 1974, despite some variations in start-up dates for particular stations, contain common elements, in terms of mix of generation, size of units and the role of nuclear power. LRFs have proposed a system expansion programme beyond the last committed station (Darlington) nuclear and coal capacity in the ratio of about 2:1.

6. The Darlington station consists of 4 × 850 MW units. LRF 48A proposes the installation of a 4 × 1250 MW nuclear plant by the early 1990s. Although a 1976 memorandum from Ontario Hydro (, Exhibit 21) suggested that 4 × 2000 MW nuclear stations might be feasible by 2000, later staff testimony indicated that such unit sizes are purely speculative and should be regarded as "blocks of generation" only.

7. Ontario Hydro's estimates in 1975 placed the twelve year expenditures associated with LRF 41A at over $49 billion; more recent estimates have placed the ten year expansion programme at a still impressive $30 billion current dollars.

8. In July of 1975, the provincial mini-budget requested a cut of $1 billion in Ontario Hydro's capital expenditures to 1985. Compliance with this request resulted in a deferral of Bruce B; subsequent generation facilities were deferred by six months in LRF 43P. In January of 1976, the Provincial Treasurer announced a limiting of capital available to Ontario Hydro for the 1976-78 period. This necessitated production of another new long range forecast, LRF 47 (later revised to LRF 48) which included cancellation of the fourth heavy water plant and a two year deferral of the third heavy water plant at Bruce, postponement of Wesleyville, Darlington, and E15 by two years, and postponement of Pickering B, Bruce B, Atikokan, Thunder Bay and W3 by one year. In LRF 48, the deferrals for Darlington and W3 were revised to twenty-two months and two years, respectively.

9. Ontario Hydro calculations of the costs associated with the deferrals and cancellations announced in February 1976 include: contract renegotiation $154 million (including deferral costs of $20.3 million); inflationary impact $69 million; Bruce HWP C: sunk costs, $26.5 million; net loss on surplus goods, $36 million; and administrative costs associated with renegotiation $1.7

million (*Hydroscope*, June 24, 1977). The initial announcement of these programme changes suggested that 1200 people might have to be laid off at the affected projects, about 400 might have to be transferred to other jobs, 2500 jobs would not be created over the next two years and 1500 jobs per year with Hydro suppliers could be affected (letter of the Chairman of Ontario Hydro to the Minister of Energy, February 11, 1978). However, when questioned at the hearings, Ontario Hydro knew of no specific analysis of the employment effects and stated that any current estimates would depend primarily on assumptions of general employment multiplier effects.

10. Some construction unions asked that Hydro not cancel any of its planned projects, despite lower growth in demand.

11. A member of the Ontario Hydro management committee on the SEPR study group reports that documentation from the study is strongest in those financial and system planning areas with which Ontario Hydro has already been involved and has a solid data base, somewhat innovative in the economic area but "will be weak in the social area and in the environmental area".

12. Arthur Hill, then Manager, Routes and Site Selection, Ontario Hydro, Transcript 145: 19,158-19,162.

13. To illustrate static energy analysis, let us assume that all inputs and useful output can be represented by a common energy unit. Then C represents the energy equivalent of the capital (material, labour etc.) required to build the plant, I is the total annual operating input (fuel, maintenance, etc.), and G is the gross annual energy output (part of I may come from G). Given C, I and G, one can calculate the payback time; i.e. number of years of operation required to produce an amount of energy equivalent to that required to build the facility and bring it on stream, as follows: Payback time (in years) = $C/(G\text{-}I)$. In a dynamic analysis some plants will come on stream as producers while others, under construction, will be consumers. The net power output of a given construction programme will depend upon the number of facilities under construction relative to the number producing energy. Some of the important parameters of a dynamic net energy model are the rate and pattern of expansion, the construction lead time, the productive lifetime of each facility, and the power input during construction and output during operation of each facility.

14. Gil Winstanley, Brian Emmett, *et al.*, *Energy Requirements Associated with Selected Canadian Energy Developments*, Department of Energy, Mines and Resources, Office of Energy Conservation, Research Report 13, Ottawa, 1977.

15. Ontario Hydro, Design and Development Division, *An Energy Analysis of the Nuclear Generating Program Defined by Ontario Hydro's Long Range Forecast—43P*, Report 76018, March 1976.

Notes to Chapter Four

1. Professor (later Lord) Rutherford's sojourn at McGill University was a particularly fruitful one. Indeed, Rutherford was awarded the Nobel Prize for Chemistry in 1908. The 1898-1907 period is usually regarded as one of the most prolific periods of research on atomic structure. Particularly notable was the publication in 1905 of Einstein's Special Theory of Relativity.

2. The first man-made self-sustained nuclear reaction was achieved by an international team headed by Professor Enrico Fermi, in Chicago on December 2, 1942, using a graphite uranium-235 "pile".

3. See, for example, Task Force Hydro, *Nuclear Power in Ontario, Report No. 3*, Toronto, 1973.

4. Present grades are in the range of 0.75 to 2.0 kg U_3O_8 per tonne.

5. The chemical properties of an element are determined by the number of protons in its atomic nucleus and by the same number (in the normal state) of extranuclear, or orbital, electrons. The latter are assumed to be distributed in "shells" around the nucleus. When an atom is "excited", an electron moves from one shell to another and electromagnetic radiation (x-rays, ultraviolet light, etc.) is emitted.

6. For an excellent introduction to atomic energy see L. Bertin, *Atom Harvest*, London: Secker & Warburg, 1955.

7. The radioactive decay sequence from Th-233 to U-233 involves a major half-life in the order of 27 days, while the U-239 to Pu-239 sequence involves a half-life of 2 days.

8. Each Pickering A CANDU reactor requires about 450 tonnes of heavy water, the value of which, at the current price of $211/kg, is $95 million.

9. To date about 1700 tonnes of spent fuel is stored at Pickering A. If its Pu-239 content could be converted into energy in a nuclear reactor, it would replace 153 million barrels of oil, assuming the latter was used to generate electricity. (Note that the oil equivalent heat value is about 51 million barrels; Ontario's oil consumption is more than 500,000 barrels per day.) At present about 270 tonnes of spent fuel is generated at the station annually.

10. It is usually assumed by agencies anticipating use of advanced fuel cycles (e.g. the fast breeder reactor) that the reprocessing plant, the fuel fabrication plant, the radioactive waste solidification and immobilization plant, and the disposal of low- and medium-level wastes

would be built on the same site. It would be a central facility and would reprocess the spent fuel from many nuclear reactors.

Notes to Chapter Six

1. The ICRP is an independent body of professional scientists set up under the sponsorship of the International Congress of Radiation. Their recommendations relating to radiation standards are published in detail in: International Commission on Radiological Protection, *Annals of the ICRP: Recommendations, adopted January 17, 1977*, ICRP Publication 26, Oxford: Pergamon Press, 1977. Exhibit 319.

2. It has been suggested that between 60 per cent and 90 per cent of human cancer is caused environmentally — much of it is due, apparently, to the release of toxic and carcinogenic agents by a whole range of industries. If these industries (e.g. transportation, chemical, food processing, mining, etc.) were subjected to the same rigorous scientific investigations as the nuclear industry, the incidence of human cancer would probably be appreciably reduced.

3. Royal Commission on the Health and Safety of Workers in Mines (Commissioner: James Ham), *Report*, Toronto: Ministry of the Attorney General, 1976.

4. American Physical Society, "Report to the A.P.S. by the Study Group on Nuclear Fuel Cycles and Waste Management", *Review of Modern Physics*, 50: 1-186, January 1978.

5. It is worth pointing out here that while many serious accidents (e.g. NRX in 1952, Windscale in 1957, Enrico Fermi FBR in 1966 and Brown's Ferry in 1975) have taken place, they cannot, by definition, be categorized as major accidents since they did not result in the release of substantial amounts of radioactivity to the environment.

6. E. Siddall, *Statistical Analysis of Reactor Safety Standards*, Ottawa: Atomic Energy of Canada Limited, 1959 (AECL-498). Exhibit 330.

7. G.C. Laurence, "Nuclear Power Station Safety in Canada", paper presented at the meeting of the Niagara-Finger Lakes Section of the American Nuclear Society, Jan. 26, 1972. Exhibit 330-3.

G.C. Laurence and F.C. Boyd, "Trends in Reactor Safety", paper presented to Nuclear Industries Fair, Technical Meeting No. 5/1, Basel, Switzerland, October 6-11, 1969. Exhibit 330-4.

8. It is important to note that, although the digital computer is central in the control (i.e. regulation) of a CANDU reactor, it is not necessarily involved in reactor shutdown. It is, however, essential in the study of the risks associated with the malfunction of key reactor components. Insofar as the role of computer modelling in risk assessments is concerned, we have neither the competence nor the facilities to assess the realism of the simulation. This is one of the major tasks of the AECB. The extent to which extremely sophisticated computer codes and programmes can be checked for realism and adequacy is a subject of central importance in the assessment of reactor safety. EPRI, NP-309, p. 1-1.

9. *Ibid.*

10. The most comprehensive study of the consequences of a major nuclear reactor accident to date is the *WASH-1400, Reactor Safety Study* (the Rasmussen Report), commissioned by the United States Nuclear Regulation Board and published in October 1975. For a summary of the Report, see Nuclear Energy Study Group, *Nuclear Power: Issues and Choices*, a report sponsored by the Ford Foundation and administered by the MITRE Corporation, Cambridge, Mass.: Ballinger, 1977, pp. 222-232.

11. Both Ontario Hydro and AECL were cross-examined by Dr. Gordon Edwards extensively on this. Liberty Pease of AECL indicated that the Rasmussen Report could be applied to a CANDU reactor; so this frequency may be realistic (Trancript 136, 17,379-17,-442). William Morison of Ontario Hydro, however, maintained his belief that the expected frequency of a meltdown in a CANDU reactor was in the order of 1 in 1,000,000 reactor years, (Transcript 204: 32,503-32,509).

12. R. Torrie and G. Edwards, *Summary Argument to RCEPP*, p. 39. Exhibit 332.

13. *Reactor Safety Study*, Appendix VI, and *Report of the Advisory Committee on the Biological Effects of Ionizing Radiation*, National Academy of Sciences, Washington: National Research Council, November 1972.

14. Electric Power Research Institute, *Performance Measurement System for Training Simulators*, interim report. Report NP-783, Project 769, Palo Alto, Calif., 1978. Also see cross-examination by J.W. Senders in Transcript 205.

15. J.R. Ravetz, "Anticipation", in the Journal of the World Council of Churches, No. 20, p.24, May 1975.

16. Dr. Terry Anderson, Ontario Hydro mortality 2nd report 1970-75 and 1976 supplement, November 1976. Exhibit 328-15. See also Robert Wilson, "Occupational Doses in the Ontario Hydro Nuclear Programme" *Health Physics*, 33: 177-182, September 1977. Exhibit 328-33.

17. H. Inhaber, *Risk of Energy Production*, Ottawa:

Atomic Energy Control Board, March 1978. (AECB-1119). Exhibit 321. An evaluation of the full cycle risks for several electrical generating technologies and solar space heating. The findings, in increasing order of risk, were natural gas, nuclear, ocean thermal, solar space heating, solar thermal electric (power tower), photovoltaics, wind, methanol from biomass, oil and coal. Most of the risks came from the acquisition and manufacture of the materials required for the technologies.

18. In 1976 the water effluent emissions from nuclear stations in Ontario, as a percentage of the AECB "permitted tritium release levels", were as follows: NPD — 5.6×10^{-2} Douglas Point — .47 Pickering — 3.6×10^{-2} For releases at Pickering from 1971 to 1975, see G.A. Pon, *Nuclear Power Reactor Safety*, submission by Atomic Energy of Canada Limited. Exhibit 28.

19. Canadian Environmental Advisory Council, *Annual Review 1976*, Ottawa, 1976, p. 63.

20. The role of human operatives is central to contingency planning: hence the importance of conducting, at regular intervals, adequately realistic rehearsals — see previous section on "The Human Factor". See also Transcript 203: 32,259-32,262 and Transcript 206: 33,-021-33,051.

21. Bruce B Generating Station will reject about 2.57×10^{13} joules/h of waste heat — of this, 0.27×10^{13} joules/h is rejected, via the moderator coolant, at a temperature of 38°C. This is ideally suited for the heating of greenhouses. About 20 per cent of the rejected moderator heat would be required for 50 ha.

22. H.E. Duckworth *et al.*, *Environmental Aspects of Nuclear Power Development in Canada*, Occasional Paper No. 2, Ottawa: Canadian Environmental Advisory Council, 1977, p. 36.

23. Although, because of the potential energy contained in the nuclear fuel removed from reactors, "irradiated fuel" is the scientifically preferred term, we have preferred to use the term "spent fuel". It is important to note that the two terms are synonymous.

24. R.W. Barnes, *The Management of Irradiated Fuel in Ontario*, a report by the Design and Development Division. 2 vols. Toronto: Ontario Hydro, 1976. (Report GP-76014). Exhibit 139, 139-1, 139-2.

25. Probably the most promising spent fuel immobilization method under consideration is the vitrification (i.e. glassification) process in which the radioactive materials are contained in molten glass which, of course, subsequently solidifies. Reference should be made to AECL brief of January 1978, submitted to the House of Commons Standing Committee on Supply and Services.

26. The case for a "central interim storage" facility is presented in detail by Ontario Hydro in Transcript 207: 33,137-33,169.

27. Royal Commission on Environmental Pollution (Chairman: Sir Brian Flowers), *Sixth Report: Nuclear Power and the Environment*, London, H.M.S.O., 1976, Chapter VIII.

28. See Note 5.

29. See Note 4.

30. Kärn-Bränsle-Säkerhet, Nuclear Fuel Safety Project: *Handling of Spent Nuclear Fuel and Final Storage of Vitrified High Level Waste*, Stockholm, November 1977.

31. Dr. F.K. Hare *et al.*, *The Management of Canada's Nuclear Wastes*, Ottawa: Department of Energy, Mines and Resources, 1977. Report EP 77-6. The members of the study group were Dr. A.M. Aikin, Dr. J.M. Harrison and Dr. F.K. Hare (Chairman).

32. R.J. Uffen, *The Disposal of Ontario's Used Nuclear Fuel*, a status report on alternative proposals for the storage, reprocessing and ultimate disposal of used fuel from CANDU reactors, Kingston: Queen's University, 1978. Exhibit 316.

33. Appearances of A.M. Aikin, J.M. Harrison and F.K. Hare, and of R.J. Uffen at public hearings of the Commission are recorded in the Transcripts, vols. 184 and 197 respectively.

34. D.A. Gray *et al. Disposal of Highly Active Solid Radioactive Wastes into Geologic Formations*, Institute of Geologic Sciences, Report No. 76/12, London: H.M.S.O., 1976.

35. Details of an agreement between the Ontario Ministry of Energy, Ontario Hydro, and AECL, in connection with the management and disposal of Ontario Hydro's spent fuel, were published in April 1978.

36. L.J. Carter, "Nuclear Wastes: The Science of Geologic Disposal seen as Weak", *Science*, 200: 1135-1137. June 1978.

37. G.M. Woodwell, "The Carbon Dioxide Question", *Scientific American*, 238: 34-43. January 1978.

Notes to Chapter Seven

1. On average, Ontario Hydro is investing something more than \$500 per kilowatt of nuclear generating capacity brought into service today, a little less for each kilowatt of hydraulic capacity, and about \$250 per kilowatt of fossil capacity. Furthermore, in addition to the generating capacity needed to meet the peak load, Ontario Hydro maintains reserve generation capacity averaging about 30 per cent of its peak load. Costs per kilowatt of transmission or distribution facilities to deliver the energy to the point of use adds over \$400/kW.

Line losses and some inefficiency in end-use application further increase the system capacity requirements.

2. Ontario Hydro's most recent capital expenditure forecast shows a reduction in the programme's cost for 1978-1986 of $4.66 billion as compared to the costs of the LRF 48A generation plan. This reflects both the cancellation of Wesleyville units 3 and 4 and an "assumed deferral" of Bruce HWP D.

3. Dr. Leonard Waverman, Professor of Economics, University of Toronto, Transcript 151: 20,383-20,384.

4. AECL Seminar, *Proposed Canadian Fuel Cycle Programme*, February 28, 1977, concluding remarks of J.S. Foster, p. 6. Exhibit 85.

5. Ontario Hydro, *Annual Report, 1977*, p. 29.

6. Transcript 202: 31,897-31,898.

7. Transcript 202: 31,908-31,920.

8. "List of Ontario Hydro Illustrations", p. 34. Exhibit 328-2.

9. Ontario Hydro, May 1978. The detailed breakdown of costs for the Darlington G.S. destined for in-service 1985-1988 (millions of current dollars): direct $2,003; indirect $340; engineering $324; interest during construction $1,047; contingencies $236; heavy water $814; commissioning (net) $343; Total $5,107 — that is (in current *dollars*), $1,502/kW.

10. A Select Committee of the Ontario Legislature, chaired by Donald MacDonald, MPP, is currently conducting an inquiry into the cost overruns at the two heavy water plants being built by Ontario Hydro at the Bruce site. The Committee is also studying the need for the third heavy water plant.

11. See *Ford-MITRE Study*, p. 9. Fisheries and Environment Canada urged consideration of "scrubbers" (Exhibit 120), but were strongly challenged on their justification by Ontario Hydro.

12. The cost of replacing the small quantities of heavy water lost during reactor operation, and of upgrading heavy water (which becomes mixed with ordinary water) to its original isotopic state can be considered as a type of "O&M" cost specific to nuclear stations.

13. The Government of Alberta has stated that it intends to ensure, by way of royalties and taxes, "that a fair price is received for this depleting non-renewable resource . . . and that all contracts for the sale of coal to out-of-province customers contain a provision for a price review at two-year intervals". Furthermore Alberta has made it clear that final decisions on the rate of exploitation of coal resources will be made in accordance with its own assessment of the economic and environmental trade-offs. Alberta Department of Energy and Natural Resources, "A Coal Development Policy for Alberta", June 16, 1976, pp. 3 and 24. Exhibit 202.

14. Dr. S. Banerjee and Dr. L. Waverman, *Life Cycle Costs of Coal and Nuclear Generating Stations*, draft report to RCEPP, April 1978. Exhibit 194.

15. *Ibid.*

16. W.G. Morison, Ontario Hydro's Director of Design and Development, indicated:

> No one can hold me to it but I would not be a bit surprised to see the Pickering reactor running until 2050, chugging out 2,000 megawatts to the system — Transcript 208: 33,297.

17. G.N. Unsworth, "Decommissioning of CANDU Nuclear Stations", in AECL, *Nuclear Power: The Canadian Issues*, April 1977, pp. 49-67. Exhibit 158.

18. U.S. Controller General, Report to Congress, "Cleaning up the Remains of Nuclear Facilities: A Multi-Billion Dollar Program", June 16, 1977. Exhibit 268.

19. Ontario Hydro, reply to interrogatory 3-5.

20. Bill C-14 (House of Commons of Canada, Third Session, Thirtieth Parliament, 26 Elizabeth II, 1977) *An Act to provide for the regulation, control and supervision of the development, production, use and application of Nuclear Energy and matters relating thereto*, First reading, November 24, 1977.

21. Ontario Hydro, *Generation Nuclear*, p.8. Exhibit 328.

22. Mr. Jennekens of the AECB stated that although the definition of what constitutes a "nuclear installation" under section 2 of the Act has not been decided by the Board, for nuclear stations it would probably be considered a four-unit station. Transcript 198: 30,996.

23. A U.S. utility is eligible for U.S. government financial protection, under the Price-Anderson Act, of up to $435 million per nuclear station if it carries the maximum private liability insurance available (currently $125 million per station). This brings the total liability protection to $560 million. It is reported that U.S. private insurers have recently been reducing their rates for this insurance.

24. Transcript 50: 7120

25. Ontario Hydro, *Generation Nuclear*, p.7. Exhibit 328.

26. The federal government's announced budget for energy research and development for fiscal year 1978-79 includes $90.3 million for nuclear and $13.6 million for renewable energy.

27. Banerjee and Waverman, *op. cit.* The study included imputed R&D costs, security, decommissioning and irradiated fuel management in nuclear plant costs.

28. See Chapter 3

29. Ontario Hydro, Chart: "Nuclear Unit Size in the Western World", April 1978. Exhibit 328-26.

30. The Commission received one carefully documented brief arguing for research support for a small scale engineering demonstration of a CANHO (Canadian Hydrogen-Oxygen) MHD electric storage system which it was claimed would provide the low capital cost peaking capacity required by a nuclear intensive system. The system would use base load electrical energy to produce hydrogen, oxygen and partially enriched heavy water in a high pressure, water electrolysis plant, store the H_2 and O_2 fuels and subsequently convert them back to electricity for peak sharing in an MHD generator. (SJT Consultants Ltd., SJTCL SB 77-3. Exhibit 196.) The Commission will review this proposal in its final report.

31. H.J. Sissons, Vice President Distribution, Ontario Hydro, speech to Owen Sound Rotary Club, April 17, 1978, p.8.

32. Ontario Hydro, *Generation Nuclear*, June, 1977, p.7. Exhibit 328.

33. Ministry of TEIGA, submission to the RCEPP, May 1976, p.34. Exhibit 18.

> It appears evident that Ontario has entered a new era in its financial evolution, one of continuous borrowing constraint. The recent actions of the Treasurer have assured the Province's ability to finance its requirements over the next few years. However, there is a prudent limit to Ontario's borrowing at reasonable rates and at this time it appears probable that, even if the Province does not borrow publicly for the next seven years, the capital markets could be unprepared to supply sufficient funds to finance [Ontario] Hydro's projected borrowing program beyond 1980.

34. The Ontario Government's announcement, on April 17, 1978, that two Wesleyville units will be cancelled will, indeed, reduce the financing deficit by $300 million.

35. J.R. Downs, *The Availability of Capital to Fund the Development of Canadian Energy Supplies*, Canadian Energy Research Institute, Study No. 1, November 1977, pp. 40-41.

36. *Resources for the Future*, Annual Report 1977, Washington, p.19.

37. Dr. P. Hill, *The Social Costs of Electric Power Generation*, RCEPP, 1977.

Notes to Chapter Eight

1. Nuclear Energy Policy Study Group, *Nuclear Power: Issues and Choices*, a report sponsored by the Ford Foundation and administered by the MITRE Corporation, Cambridge, Mass.: Ballinger, 1977, p. 51.

2. CNA submission to Debate Stage Hearings on Nuclear Power, p. 4. Exhibit 260.

3. Ontario Hydro submission to Debate Stage Hearings on Nuclear Power, p. 9. Exhibit 328-1. Lifetime capacity factor 40 per cent. As Western Canadian coals are increasingly blended with U.S. coals the import component, of course, declines.

4. Ontario Hydro, *Hydro Purchasing*, 1977.

5. Ian A. Forbes, "Our Energy Future: Getting There from Here", paper presented to the 34th Annual National Conference of the American Public Power Association, Toronto, June 15, 1977. Exhibit 138.

6. CNA submission to RCEPP. Exhibit 261. The statement was originally made by a vice president of Wood Gundy, Dr. Peter Campbell, to the 1977 CNA annual meeting.

7. CNA submission to Debate Stage Hearings on Financial and Economic Factors. Exhibit 191.

8. Ontario Hydro, *Finance and Economics*, p. 19. Exhibit 188.

9. CNA submission to Information Hearings, p. 44. Exhibit 25.

10. EEMAC, Nuclear Power in Ontario: Part A, *Economic Considerations*, April 1978, p.3. Exhibit 151.

11. James F. Maclaren Ltd. and Slater Energy Consultants Inc., *A Study for the Export of Electrical Power*, April 1977, "Balance Sheet", Ministry of Industry and Tourism submission to RCEPP. Exhibit 200.

12. Ontario Hydro, *Annual Report 1977*, p. 10.

13. Ontario Hydro itself noted that income and employment multipliers for utilities are significantly below the provincial average. Ontario Hydro, *Socioeconomic Factors*, pp. 4.1-3. Exhibit 7.

14. Herbert Inhaber, *Risk of Energy Production*, Ottawa: AECB, March 1978.

15. U.S. Office of Technology Assessment, *Application of Solar Technology to Today's Energy Needs*, Vol.1, June 1978.

16. M. Nastich, Vice President Resources, Ontario Hydro, Debate Stage Hearings Transcript 149, August 11, 1977.

17. Debate Stage Hearings Transcript 181: 27,137 December 7, 1977.

18. Further detailed to 4-5,000 uranium mining companies; 6,000 AECL; 6,000 Ontario Hydro; 2,000 other Canadian utilities. Transcript 181: 27,189-20.

19. Transcript 150: 20,202-6. Alan Wyatt of the CNA suggested that most difficulty would be experienced with the 13-14,000 highly skilled component of the 17,-600 hourly paid — but some of these are engineers with

skills "more easily adaptable than some of the scientific ones. So much depends, of course, on alternative employment opportunities." He also noted that the 5,100 professionals (about half at AECL) are quite specialized and would be harder to retrain. Transcript 150: 20,202-20,223.

20. Ontario Hydro undertook to table in the total system hearings an "SEPR Modelling run" which portrays the employment effect of a decision to add no more nuclear units after the Darlington station.

21. CCNR *The Nuclear Option: Time to Stop and Think*, June 30, 1977. Exhibit 156-1.

22. AECL *Final Argument*, p.88. Exhibit 158-4.

23. Institute for Energy Analysis, Oak Ridge Associated Universities, *Economic and Environmental Implications of a U.S. Nuclear Moratorium, 1985-2010*, ORAU 76-4, September 1976; David J. Behling, Jr., *The Impact of Alternative Nuclear Moratorium Legislation on the U.S. Economy*, Brookhaven National Centre for Analysis of Energy Systems, Upton, N.Y.: Brookhaven National Laboratory, December 1976, BNL 50604.

24. The Oak Ridge Study expressed concern about particulate emissions from the extra coal burned but said that with proper control SO_2 and other gaseous emissions could be lower in 2000 than present levels, with or without a moratorium. A U.S. nuclear moratorium by itself would not significantly affect atmospheric CO_2 concentrations, but if followed by other countries such that 20 per cent of the world's fossil fuels were burned, this could lead to unacceptable changes in the world's climate. Oak Ridge, *op.cit.*, pp. 1-10.

25. Behling, *op.cit.*

26. Ontario Hydro puts the figure at 25,000. *Generation Nuclear*, p. 24. Exhibit 328.

27. CNA submission to Debate Stage Hearings on Nuclear Power, p.5. Exhibit 260.

Notes to Chapter Nine

1. The uranium requirements to fuel all stations to Darlington for 30 years at 80 per cent capacity factors are approximately 60,000 tonnes. The Denison-Preston contracts total about 76,000 tonnes. The difference of 16,000 tonnes could fuel an additional 4,000 MW for 30 years at 80 per cent capacity factor. About 4.2 tonnes of uranium is required to fuel 1 MW for 30 years at an 80 per cent capacity factor.

2. *Uranium: Resources, Production and Demand*, a Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency, Paris, 1977.

3. *Ibid*

4. The uranium supply situation in the United States is very similar. According to Professor L.T. Silver, California Institute of Technology, the uranium supply and demand curves will cross some time between 1982 and 1990, unless new resources are discovered and developed. He stresses that the U.S. must "sharply increase its rate of successful uranium exploration". See "The Uranium Crunch", *Technology Review*, June/July 1978. p.24.

5. *1977 Assessment of Canada's Uranium Supply and Demand* Ottawa, Ministry of Supply and Services, 1978. p.22

6. "The Uranium Crunch", *Technology Review*, June/July 1978. p.24

Notes to Chapter Eleven

1. The nuclear weapons proliferation question is dealt with comprehensively in T. Greenwood, H.A. Feiveson and T.B. Taylor, *Nuclear Proliferation: Motivation, Capabilities and Strategies for Control*, Washington: D.C.: Council on Foreign Relations, 1977.

2. There are, of course, probably tens of thousands of nuclear weapons already in existence, mostly in the arsenals of the United States and the U.S.S.R. Furthermore, although not insignificant in terms of their destructive potential, smaller numbers of nuclear weapons and less sophisticated delivery systems have been developed by the other nuclear powers: Britain, France, the People's Republic of China, and most recently India.

3. The "critical mass" of U-235, U-233 or Pu-239 required for a nuclear weapon is determined by the degree of purity of the fissionable isotope. The purer the isotope, the smaller the critical mass. However, natural uranium, enriched with as little as, for example, 30 per cent U-235, will "go critical" and create an explosion if a large enough quantity is assembled. The yield of a nuclear weapon depends, of course, on many other factors, the most important of which are probably the rate at which the two sub-critical components are brought together and the "geometry", material and construction of the weapon.

4. Technology designed to detect the diversion of nuclear materials from on-power fuelled reactors (e.g. CANDU) is being tested at the Douglas Point Generating Station.

5. David J. Rose and R.K. Lester, "Nuclear Power, Nuclear Weapons and International Stability", *Scientific American*, April 1978, pp. 45-57.

6. The concept of "safeguards" is admirably explained in Nuclear Power Policy Study Group *Nuclear Power:*

Issues and Choices, Cambridge, Mass.: Ballinger, 1977, p. 292:

> Safeguards over the use of indigenous or imported nuclear material or facilities play an important but limited role in preventing proliferation. They do not in themselves limit the capability to make nuclear weapons; they do not prevent misuse of nuclear capabilities or prevent proliferation. Nevertheless, the do help deter proliferation and create an international atmosphere in which a non-proliferation regime is possible.

7. *The Windscale Inquiry*, report by the Honourable Mr. Justice Parker presented to the Secretary of State for the Environment on January, 26, 1978: Vol. 1, *Report and Annexes* 3-5, London, 1978.

8. Canada's safeguards systems is perhaps the most stringent in the world. Our present policy resulted in the cessation of nuclear exports to both India and Pakistan (who refused to accept Canadian safeguards) and in an embargo which lasted for more than a year on the sale of uranium to Japan and certain members of the European Economic Community.

9. Amory Lovins, *Soft Energy Paths: Toward a Durable Peace*, Cambridge, Mass.: Ballinger, 1977. Table 11-1 indicates that up to March 31, 1976, approximately 1.1 tonnes of uranium-235 enriched above the 20 per cent level had entered Canada from the United States.

Notes to Chapter Twelve

1. Eldorado Nuclear Limited and Atomic Energy of Canada Limited, federal Crown corporations, currently dominate much of the front-end of the fuel cycle and potentially the back-end as well. Ontario Hydro, the only utility in the province operating nuclear reactors, is also publicly owned. Part II of the new Nuclear Control and Administration Act indicated clearly that the federal government intends to become more involved in the commercial aspects of nuclear power, paricularly as related to the foreign sales of uranium and nuclear reactors. There is, therefore, an implicit linkage of nuclear power to government policy and an implied accountability of governments for the decisions of these corporations.

2. The economic benefits and the energy potential available to Canadians from our uranium base and from CANDU technology are significant. Consequently, it is against these benefits that the regulators must objectively assess risks to health, safety and the environment.

3. A.M. Weinberg and R.P. Hammond, "Global Effects of Increased Use of Energy", in *Peaceful Uses of Atomic Energy*, proceedings of the Fourth International Conference of the International Atomic Energy Agency, Geneva, September 7, 1971.

4. The Ontario Energy Board held fifty-eight days of public hearings on this subject from January 21 to June 3, 1974.

5. "Prescribed substances" are defined in the existing legislation as "uranium, thorium, plutonium, neptunium, deuterium, their respective derivatives and compounds and any other substances that the Board may by regulation designate as being capable of releasing atomic energy, or as being requisite for the production, use, or application of atomic energy".

6. Mission-oriented research is called for when additional technical information would be valuable to supplement or confirm information supplied by an applicant or to provide answers to questions of a broad nature that apply to more than one licensing activity by the AECB. The National Research Council, since April 1, 1976, has been responsible for providing grants to universities in support of basic research in the nuclear field.

7. Royal Commission on the Health and Safety of Workers in Mines, *Report*, Toronto, 1976, pp. 86-87.

8. It should be noted that the vague terms of the existing Act are not surprising in view of the fact that in 1946 nuclear fission power was at a very early stage of development.

9. Ministry of the Environment submission to RCEPP, December 1977. Exhibit 259.

10. The Darlington Nuclear G.S., which was at an advanced stage of planning when the Act was passed, was exempted from the provisions of the Act on July 25, 1977, because "undue delay and expense" would result and could have had very serious consequences for Ontario Hydro's ability to meet the demand for electricity. However, the Ministry of the Environment, the Ministry of Energy, and Ontario Hydro have agreed that all future major stations will undergo environmental assessment. It should be noted that hearings will be held at the discretion of the Minister of the Environment.

11. Section 91 of the British North America Act gives the federal government the right to make laws for the peace, order and good government of Canada with respect to all matters not coming within those subjects assigned exclusively to the provinces under section 92. Two of those subjects, "property and civil rights in the provinces" and "matters of merely local ... nature in the province" have been debated in hundreds of jurisdictional disputes. The result of many of these cases has led to the conclusion that if a work or undertaking is within the jurisdiction of the federal government, provincial legislation attempting to regulate or license that work is *ultra vires*.

There is a serious question of whether Ontario's Environmental Assessment Act would be held *ultra vires*

if it were used as justification for the regulation or control of the siting and construction of a nuclear generating station. The authority of the federal government to deal exclusively in nuclear matters first came before the Ontario courts in *Pronto Uranium Mines Limited v The Ontario Labour Relations Board (1956)*. In *Algoma Uranium Mines Limited v The Ontario Labour Relations Board (1956)*, the judgement stated that:

> In this day it cannot be said that the control of atomic energy is merely a local or Provincial concern and in my opinion it is a matter which, from its inherent nature, is of concern to the nation as a whole and the Act and Regulations are within the powers of Parliament to make laws for the peace, order and good government of Canada.

This position was subsequently upheld in the 1973 case of *Denison Mines Limited v The Attornery General of Canada.*

12. See Chapter 6.

13. On the instructions of the Atomic Energy Control Board, its staff, together with representatives of the reactor safety advisory committee, of the utilities using nuclear power, and of the designer, are documenting the procedures, guidelines and standards which have never been clearly set down and placed before the Board. The committee is known as the Interorganization Working Group.

14. A list of these studies is included in the CNA submission, August 1977. Exhibit 191.

15. It is anticipated that the Environmental Assessment Board will deal with all of these questions.

16. Institute for Aerospace Studies, University of Toronto, submission to the Debate Stage Hearings. Exhibit 152.

17. There have been three key suggestions for ways to shorten the lead times required for the development of electric power facilities. These are:

- *Generic hearings*, held on a specific topic (for example, the decommissioning of nuclear reactors). Such hearings may allow a topic to be separated from the consideration of licensing a specific reactor, while at the same time allowing for full consideration of some of the broader aspects relating to nuclear power.
- *Separation of site selection hearings from project approval hearings.* This separation may streamline the approvals process, but it may also confuse the key issues of need, safety and environmental impact because it may prove difficult to untangle these issues from one hearing to another.
- *Standardize reactor unit size and design.* Some believe this practice would reduce the regulatory review period but others believe it would not lead to satisfactory advancement in performance and safety.

Notes to Chapter Thirteen

1. Ontario Ministry of Energy, *Ontario's Energy Future*, Toronto, April 1977.

2. Ontario Hydro's estimate of the capital costs in current dollars, including escalation for capacity coming into service in 1985-1988, is \$1500/kW (Darlington) and in 1995 is \$2300/kW. Ontario Hydro submission, *Generation Planning Processes*, Figure 11-12. Exhibit 21. The figure \$2000/kW is used as an approximate average post-Darlington capacity cost.

3. Nuclear power stations provided 27 per cent of Ontario Hydro's total energy generated in 1977. The Pickering units operated with an over 90 per cent capacity factor throughout the year. The first two Bruce units also operated at high capacity factors from their in-service date, September 1. While the nuclear stations' average factor was greater than 90 per cent from their in-service dates, the year long capacity factor of the almost 3800 MW of nuclear power was 70 per cent.

4. This estimate of the potential of biomass, especially that of energy plantations, is appreciably lower, on a per capita basis, than a recent Swedish estimate. T.G. Johansson and Peter Steen, of the Swedish Secretariat for Future Studies, "Solar Sweden", *AmBio*, Vol. 7, No. 2, p.70, have developed a total energy scenario for the year 2015 which shows how the country's energy supply could be based entirely on domestic and renewable energy sources. Notably almost 50 per cent would be contributed by biomass (energy plantations) — this is based on the possible use of 2.9 million hectares for energy plantations with an average yield of 90 MWh per hectare per year. With a massive effort Ontario should be able to achieve comparable results within forty years.

Notes to Annex E

1. Ontario Hydro submission to Debate Stage Hearings. Exhibit 107, Appendix 1.

2. *Ibid.*

3. Informal meeting with Hydraulic Section, Ontario Hydro, April 14, 1978.

4. Upgrading of hydroelectric facilities installed or committed to date totals 151 MW of installed dependable power.

5. Ontario Hydro, submission to RCEPP, Debate Stage Hearings. Exhibit 107.

6. The Ottinger Act of May 24, 1977, authorized the

Federal Power Commission "to issue low interest loans and grants to prove the economic, technical, and environmental feasibility of utilizing dams all across the country" for electricity production.

7. "INCO Proposal for Hydro-Electric Development on the Spanish River", INCO presentation to the Sierra Club and Wilderness Canoeing Club, 1977.

8. These technologies will be reviewed in detail in the Commission's final report.

9. Energy, Mines and Resources Canada, *An Energy Strategy for Canada*, Ottawa, 1976, Table 11.

10. Fisheries and Environment Canada, submission to Debate Stage Hearings. Exhibit 120.

11. Morris, Wayman Limited, *Wood-Fired Electricity Generation in Eastern Ontario*, Toronto, 1978.

12. For comparison with a projected renewable energy scenario for Sweden, see T.B. Johansson and Peter Steen, "Solar Sweden", *AmBio*, Vol. 7, No. 2, p. 70. Noteworthy is the fact that the authors assume 2.9 million hectares in Sweden for energy plantations (with an average yield of 90 MWh per hectare per year); this represents 6 to 7 per cent of the total land area. The aggregate energy (for 2015) assumed generated by biomass is 351 Terawatt hours (TWh) compared with 217 TWh from hydraulic and solar energy combined. The total from renewable sources is 568 TWh, which matches Sweden's total projected energy demand for the year 2015.

13. A number of estimates were presented to the Commission during the Debate Stage Hearings.

14. Dow Chemical, submission to Public Information Hearings. Exhibit 39.

Annex A

Terms of Reference

The Royal Commission on Electric Power Planning has been empowered under Order-in-Council number 2005B/75 dated the 17th day of July, A.D. 1975 and instructed to:

1) Examine the long-range electric power planning concepts of Ontario Hydro for the period 1983-93 and beyond and to report its findings and recommendations to the Government, so that an approved framework can be decided upon for Ontario Hydro in planning and implementing the electrical power system in the best interests of the people of Ontario;

2) Inquire comprehensively into Ontario Hydro's long-range planning program in its relation to provincial planning; to domestic, commercial and industrial utilization of electrical energy; to environmental, energy and socio-economic factors, including but not limited to matters such as electric load growth, systems reliability, management of heat discharged from generating stations, interconnecting and power pooling with neighbouring utilities, export policy, economic investment policy, land use, general principles on the siting of generating stations and transmission corridors, efficient utilization of electrical energy and wise management (conservation) of primary energy resources, power generation technology, security of fuel supplies and operational considerations;

3) Deal primarily with the broader issues relating to electric power planning, and thus serve to alleviate the need for re-examination of these issues at subsequent hearings of other hearing bodies on specific details such as siting, rates, etc.;

4) Consider and report on a priority basis on the need for a North Channel Generating Station, a second 500 k.V. line from Bruce, a 500 k.V. supply to Kitchener, a 500 k.V. line from Nanticoke to London, and a 500 k.V. line in the Ottawa-Cornwall area, and other projects as may be directed by the Lieutenant Governor in Council.

Paragraph 4 was amended and supplemented under O.C.3489/77 dated the 14th day of December, A.D. 1977 to include that the Royal Commission on Electric Power Planning be instructed and empowered to complete its examination of issues relating to nuclear power, to prepare an interim report of its opinions and conclusions in this area, including the extent of the need for nuclear as a component of Ontario's future energy supply and the proportion of nuclear power in Ontario Hydro's future generating capacity, and to provide such report on or before the 30th day of June, A.D. 1978.

Paragraph 4 was further amended under Order-in-Council dated the 12th day of July, 1978, as follows:

A) Having concluded its hearings with respect to paragraphs 1, 2 and 3 of its terms of reference;

i) For the geographic area of Ontario south of Bruce Nuclear power development and west of a line between Essa transformer station and Nanticoke generating station, consider and report to the Minister of Energy on or before May 31, 1979 on load growth in the area up to the end of 1987 and from 1987 to the year 2000, the capability of existing and committed bulk power generation and transmission facilities to supply this load to the area taking into account Government policy with respect to the use of interconnections with neighbouring utilities, and the resulting date at which additional bulk power facilities, if any, will be needed, but excluding consideration of the specific nature of the additional bulk power facilities which may be required and of their locational and environmental aspects; and

ii) For the geographic area of Ontario east of Lennox generating station, consider and report to the Minister of Energy on or before June 30, 1979 on load growth in the area up to the end of 1987 and from 1987 to the year 2000, the capability of existing and committed bulk power generation and transmission facilities to supply this load to the area taking into account Government policy with respect to the use of interconnections with neighbouring utilities, and the resulting date at which additional bulk power facilities, if any, will be needed, but excluding consideration of the specific nature of the additional bulk power facilities which may be required and of their locational and environmental aspects;

B) Provide the Government with its report and recommendations on paragraphs 1, 2 and 3 of these terms of reference on or before October 31, 1979.

[*This means that original number 4 has been deleted and replaced with the above.*]

Annex B

Energy Units

One of the difficulties in discussing energy problems relates to the wide range of units currently in use as measures of energy. For example, commonly used energy units are kilowatt hours (kWh), British thermal units (Btu), and kilocalories (kcal) which can be derived from tons and metric tonnes of coal, barrels of crude oil, or cubic feet of natural gas. Comparison of the "energy content" of a variety of sources on an absolute basis is difficult because of this variance in terminology. In this Interim Report we have used the generally accepted units of energy, as well as megajoules (MJ), the internationally accepted standard unit for energy. The following conversion factors have been used:

1 MJ = 0.2778 kWh
= 947.8 Btu
= 238.8 kcal

1 Btu = 1.055 kJ
= 2.931×10^{-4} kWh
= 252 cal

1 ton of coal = 22 to 28 $\times 10^6$ Btu
= 23.21 to 29.54 $\times 10^3$ MJ
(depending upon the quality of the coal)

1 barrel of crude oil = 5.8×10^6 Btu
= 6.12×10^3 MJ

1 cubic foot of natural gas = 1.03×10^3 Btu
= 1.09 MJ

Annex C

State of the Inquiry

The Royal Commission on Electric Power Planning was established in July 1975 in response to concerns expressed by several individuals and public interest groups regarding Ontario Hydro's long range plans for the development of Ontario's electric power system. Recognizing the public interest in the impact of electric power development, the Commission has always considered effective widespread public participation to be essential to the success of its inquiry. In keeping with this aim, we have been more concerned with broad planning principles than with narrow technical details. We summarize below the major stages of the inquiry. As well we outline our programme of seminars, workshops and symposia and list the people and organizations who presented briefs during the nuclear debate stage hearings.

Preliminary Meetings

The process of open planning and public participation began in the autumn of 1975 with a series of informal Preliminary Meetings, which were held in seventeen locations around the province. The purpose of these meetings was to determine the issues which were of most concern to the public (one-third of the submissions mentioned nuclear power as being of major concern), and to establish procedures for wide participation. Written submissions were received from 265 groups and individuals, and the Commission heard 163 oral presentations. Over 6,000 people attended the Preliminary meetings. The Commission's 1st Report highlights many of the issues and areas of concern brought forward by the public at this stage.

Public Information Hearings

Subsequent to the preliminary meetings, the Commission organized a series of Information Hearings. These were aimed at gathering information on the "whats" and "hows" of current practices, the object was to build a readily available data base for both the Commission and the public.

The first stage began March 31, 1976 and continued, in various cities and towns in the province, until July 27, 1976. Ontario Hydro presented information on its current procedures and its projections for the future in 16 areas. The provincial ministries of Agriculture and Food, Energy, Environment, Health, Housing, Industry and Tourism, Natural Resources, and the Ministry of Treasury, Economics and Intergovernmental Affairs also gave information at this stage and the Commission brought in experts in relevant fields to cross-examine the Ontario Hydro and government witnesses. The public participated actively in these hearings.

The second stage of the Information Hearings was held in Toronto from November 2, 1976 to January 20, 1977 – public interest groups, associations and industries made submissions during this stage.

The Meetings in Northern Ontario

In August and September 1976, members of the staff of the Commission visited five remote communities in Ontario's far north, meeting with Cree and Ojibway Indians in Mattagami, Attawapiskat, Fort Hope, Webequie, and Winisk. The Commission received clear messages from the native people that they wanted to be involved in Ontario's debate on energy planning. During the visit a tragic plane crashoccurred which took the lives of ten dedicated people involved in the Commission's work. Today this tragic event remains a sad remembrance. Our report entitled *The Meetings in the North* summarizes the discussions and findings of the tour – it is dedicated to those who lost their lives.

Debate Stage Hearings

After the completion of the Information Hearings, a series of Issue Papers was prepared relating to concerns voiced during the preliminary meetings and the Public Information Hearings. Nine Issue Papers were published; each addressed a specific area of concern:

Nuclear Power in Ontario
The Demand for Electric Power
Conventional and Alternate Generation Technology
Transmission and Distribution
Land Use
Financial and Economic Factors
Total Electric Power System
The Decision-Making Framework and Public Participation
An Overview of the Major Issues

The Issue Papers have been used as a focus for the debate stage hearings. Each set of hearings has commenced with a public panel discussion led by recognized experts in the field.

The Debate Stage Hearings have provided opportunities for debate and discussion of the complex issues raised during the Preliminary Meetings and have been effectively supported by the in-depth information provided during the Public Information Hearings. In a real sense the question "why" has been central. Because of public interest, the hearings were extended from the originally planned five-month period May 17 to October 27, 1977, to the end of January 1979. They began with the Demand issue, then moved to Conventional and Alternate Generation Technology, the Nuclear issue, Transmission and Land Use, and Financial and Economic Factors. The nuclear hearings generated great interest; they took a total of 63 days for 52 submissions, from June 23 to July 13, 1977 and from September 27, 1977 to April 5, 1978; in camera hearings on nuclear plant security were held in May 1978.

Of the 52 submissions, 29 were anti-nuclear on a long- or short-term basis, 18 were pro-nuclear, and 5 were considered to be neutral. Those who submitted briefs on the nuclear issues are listed below:

W.G. Artiss, New Brunswick
Atomic Energy Control Board, Ottawa, Ontario
Atomic Energy of Canada Limited, Ottawa, Ontario
E. Best, Toronto, Ontario
N. Braden, Madoc, Ontario
R. Bramfitt, North Bay, Ontario
H. Burkhardt and R. Szmidt, Toronto, Ontario
E. Burt, Manitoulin Island, Ontario
Canadian Coalition for Nuclear Responsibility, Ottawa, Ontario
Canadian Manufacturers Association, Toronto, Ontario
Canadian Nuclear Association, Toronto, Ontario
Chemical Institute of Canada, Toronto, Ontario
Confederation College, Thunder Bay, Ontario
Citizens Opposing Radioactive Pollution, Madoc, Ontario
Conservation Council of Ontario, Toronto, Ontario
Electrical and Electronic Manufacturers Association, Toronto, Ontario
Federation of Engineering and Scientific Associations, Toronto, Ontario
Fisheries and Environment Canada
Fusion Energy Foundation, Toronto, Ontario
Greenpeace Foundation London, London, Ontario
H.K. Hare, Toronto, Ontario
S.T. Hunnisett, Thunder Bay, Ontario
Institute for Aerospace Studies, Toronto, Ontario
W.B. Lewis, Deep River, Ontario
A. Lovins, London, England
J. McNamee, Toronto, Ontario
T. McQuail, Lucknow, Ontario
Rev. S. Mo, Hamilton, Ontario
M. Mostert, Guelph, Ontario
National Farmers Union, Crysler, Ontario
National Farmers Union, Guelph, Ontario
Ontario Coalition for Nuclear Responsibility, Seaforth, Ontario
Ontario Hydro Employees' Union, Toronto, Ontario
Ontario Mining Association, Toronto, Ontario
Ontario Ministry of the Environment
Ontario Peoples Energy Network, Ottawa, Ontario
R. Paehlke, Peterborough, Ontario
People Against Nuclear Development Anywhere, Prescott, Ontario
Pollution Probe — Ottawa, Ottawa, Ontario

Preservation of Agricultural Lands Society, St. Catherines, Ontario
Save the Environment from Atomic Pollution, Port Hope, Ontario
L.C. Secord, Toronto, Ontario
Serpent River Indian Reserve, Ontario
Sierra Club of Ontario, Toronto, Ontario
P.W. Sullivan, Tweed, Ontario
R.J. Uffen, Kingston, Ontario
University Women's Club of North York, Toronto, Ontario
Voice of Women, Toronto, Ontario
Walk for Life, Toronto, Ontario
Whitefish River Indian Reserve, Ontario
P. Whittaker, Gilmour, Ontario

Public Information and Participation Activities

In addition to holding hearings, the Commission has also been engaged in an education process via the Outreach programme and the seminars and workshops which have been held on various topics.

The Outreach programme and utilization guidebook helped to establish lines of communication with many schools, colleges and community groups. The Commission has also provided speakers for meetings around the province, and has co-operated with TV Ontario in the production of a two-hour special on energy. A number of seminars and workshops have been held, the first of which was a three-day symposia in November of 1976 on "Ontario's Electric Future". It was aimed primarily at obtaining information from the academic and industrial communities. The next event was a three-day workshop in March of 1977, called "Ontario's Futures and Energy Planning". This was an experiment in interaction among various sectors of the community, involving these representatives in planning the future of Ontario and the methods which could be used. In September of 1977, as a beginning to the extended nuclear hearings, the Commission sponsored a one-day seminar on the nuclear issue, at which Sir Brian Flowers, formerly Chairman of the United Kingdom Royal Commission on Environmental Pollution, was one of the guest speakers. In December of 1977 another one-day seminar on "Energy, Jobs and the Economy — Labour's Viewpoint" was held, at which senior officials from the Ontario Federation of Labour and the Canadian Labour Congress were guest speakers.

All Public Information Hearing exhibits and transcripts are on file in four depository libraries in Ontario — London, Ottawa, Sudbury, and Thunder Bay. The Information Centre at the Commission has a full set of all exhibits and transcripts of the hearings. Ottawa also has a set of transcripts of the Debate Stage Hearings.

The Commission has funded research reports by both individuals and consultants and by interest groups. Funds have also been dispersed for both individuals and groups to make submissions, especially during the main hearings when all meetings were held in Toronto, and for groups to attend and take part in the cross examination of such organizations as Atomic Energy of Canada Limited and Ontario Hydro.

Annex D

Radiation and Radiation Standards

Natural radioactivity was discovered in 1896 when Becquerel showed that certain uranium compounds emit penetrating radiation. Radioactivity involves the emission of particles from the nuclei of the unstable atoms of radioisotopes. Most radioisotopes are isotopes of heavy elements (above the element busmuth in the Periodic Table), and their radioactivity is due essentially to the unstable nature of the proton-neutron ratios and configurations in their atomic nucleii. To achieve stability, radioisotopes may emit the following types of radiation:

- **α-particles** — These particles consist of two protons and two neutrons tightly bound together as in the nucleus of a helium atom. Because of their comparatively high mass, and electric charge, α-emissions have a short penetrating range in human tissues (about 4 hundredths of a millimetre), but a strong ionizing effect that can induce cancer in certain cells. For example, inhalation of finely powdered plutonium-239, an α-emitter, may induce cancer of the lung.

- **β-particles** — These particles are electrons emitted when a neutron is transformed into a proton. β-particles can also be positively charged (positron) if a proton becomes a neutron. These particles are emitted from the nucleus with a broad range of velocities. The higher the velocity, the greater their penetration of human tissue, the greater the ionizing effects, and hence the greater the cellular damage created. Because of their extremely small mass, compared with α-particles, β-particles have much greater penetrating power but much less ionizing power.

- **γ-rays** — γ-rays are similar to x-rays but with shorter wave lengths and greater penetration. γ-rays can be regarded in some respects as very penetrating electromagnetic radiation or, on the other hand, as "photons," which have the properties of extremely minute particles. γ-rays are emitted from a nucleus when it is in an "excited" energy state. Their emission does not change either the mass of the nucleus or the chemical properties of the atom.

  γ-rays are the most penetrating radiation known to man. For example, very hard γ-rays can penetrate many feet of concrete, two or three feet of steel, and a foot or two of lead. This type of radiation constitutes the major hazard associated with nuclear power and especially the operation of a nuclear reactor, although the biological damage caused by α and β-particles in certain circumstances may be just as critical.

- **Neutrons** — Although a comparatively rare process, neutrons are emitted when a nucleus is in a highly excited state. For our purposes, we can ignore this category of radiation. It should be noted, however, that neutrons, because they have no electric charge, have very high penetrating properties.

By definition, all radioisotopes decay emitting one of these forms of radiation. The rate of decay is measured in terms of the "half-life" of the radioisotope which is defined as the time required for one half of the atoms originally present to decay. Thus, in the time interval equal to one half-life, the number of atoms and the original activity, or rate of radioactive disintegration, will be reduced by a factor of 2; at the end of the second half-life, the number of atoms and their original activity will be reduced by a factor of 4. This process is termed "exponential decay." Radioisotopes with very short half-lives decay very rapidly; those with very long half-lives decay very slowly.

The following are the half-lives of some typical radioisotopes:

Uranium-238 — 4.5×10^9 years
Plutonium-289 — 24.4×10^3 years
Radium-226 — 1.602×10^3 years
Caesium-137 — 30 years
Strontium-90 — 28 years
Krypton-85 — 9 years
Iodine-131 — 8 years

Xenon-135 — 9.2 hours
Oxygen-15 — 2 minutes
Lithium-8 — 0.9 seconds

Radiation Units

The most widely used unit to define the amount of radioactivity is the curie. The unit is defined in terms of the number of disintegrations of a radioisotope that occurs per second. Formally, the curie is that amount of a radioisotope that undergoes 3.7×10^{10} disintegrations per second.

Measurement of Radiation Dose

The basic unit used to measure radiation dose is the "rad" or "radiation absorbed dose". One rad is the amount of radiation that would cause 0.01 joules of energy to be absorbed by 1 kilogram of mass. Throughout this report we have used a derived unit called the "rem," (Roentgen Equivalent Man), which is defined as the unit of ionizing radiation that produces the same tissue damage from any radioactive source ; it is equivalent to a given amount of energy (100 ergs) of x-rays per gram of biological tissue. The ionizing radiation doses associated with nuclear power station emissions are normally measured in rems or millirems per year, and their effect on biological tissue is cumulative. In the event of a serious nuclear reactor accident, radiation doses would be measured in rems per hour and per day as well as per year.

Highly specialized instruments are used to monitor radiation both in generating stations and outside them. For example, "γ-fields" are detected using single crystal scintillation counters and pulse height analysers. Neutron radiation is measured by the activation of manganese foil, and β-radiation is measured using conventional Geiger-counter techniques. The Radiation Protection Bureau of Health and Welfare Canada provides a film badge detection service for all workers entering radiological zones in all nuclear generating stations. The film badges are worn for a period of two weeks and are subsequently processed in Ottawa. The film indicates whole body exposure, and measures dose equivalent directly in rems. The whole body dose is normally due to γ-radiation. However, because the film badge is only capable of measuring γ-radiation exposures, an attempt is also made to obtain a measure of skin dosages of β-radiation, but insofar as plant personnel are concerned, the external γ-radiation exposure is normally the factor that determines the time an individual worker spends in a particular work area.

A computer programme known as the "Dose Control Programme" has been developed at Pickering to handle all data obtained from the γ and β-radiation monitors. At the end of every two week monitoring period, reports are obtained that give the up-to-date totals for both the external and internal doses received by each worker. These are used to limit the further exposure of each worker and, at the end of each quarter, the dose data are transferred from the computer files to long-term dose record files for all employees at the generating station.

The following listing indicates the relative doses of ionizing radiation from a variety of natural and man-made sources.

Radiation doses to average general population — millirems per year
Cosmic rays (average) — 44.0
Terrestrial radiation (natural sources) — 58.0
Global fallout — 4.0
Medical diagnostic x-rays — 72.0
Radiopharmaceutical radiation — 1.0
Colour television (1 hour per day) — 2.0
Nuclear power (maximum radiation dose at station fence) — 2.0
Miscellaneous — 3.0
Source: Atomic Energy of Canada Limited

The data in the table should be put into perspective. As indicated below the average dose to bone marrow from various diagnostic x-ray procedures involves appreciably higher doses than those from all natural causes and these are far greater than the average radiation dose from nuclear power.

Mean bone marrow dosage from x-rays — millirems per year
Dental (full mouth) — 20
Chest — 40
Abdomen — 100
Stomach and gastrointestinal tract — 300
Lower gastrointestinal tract — 600
Source: Based on data from ICRP in 1970.

Radiation from Nuclear Power Stations

The radioactive materials that may be released from nuclear power stations can be classified as either "activation products" or "fission products." The former result from the bombardment by neutrons of such materials in the reactor as air, coolant, and fragments of metal in the coolant. Fission products result directly from the splitting (fission) of uranium-235 nuclei; these products are lighter atoms such as strontium, cobalt, iodine, caesium, xenon, etc. Fission products, which are usually radioactive with a broad range of half-lives, are formed in the fuel, but, under certain comparatively rare circumstances, they may find their way into the coolant system.

The principal radioisotopes released in a nuclear reactor are shown below. The maximum limits for the radioactivity that may be released are designated in the operating licence issued to each generating station by the Atomic Energy Control Board. The limits set generally follow the recommendations of the International Commission on Radiological Protection (ICRP).

Some common radioisotopes, their classification and half-life, produced in CANDU

Tritium — Activation Product — 12 years
Argon-41 — Activation Product — 1.8 years
Krypton, Xenon — Fission Product — hours-days
Iodine-131 — Fission Product — 8 days
Caesium-137 — Fission Product — 30 years
Caesium-134 — Fission Product — 2 years
Cobalt-60 — Activation Product — 8.3 years

Radiation Standards

Several highly prestigious commissions, committees and institutions have been established during the past thirty years with the major purpose of assessing the health hazards of exposure to radiation. Concomitantly, these bodies have considered basic radiation standards and limits. All international, regional, and national committees on radiation exposure recommend that, except for radiation therapy, all human exposure to radiation should be kept to an absolute minimum. In Canada the legally established body for setting radiation standards is the Atomic Energy Control Board (AECB). The Board relies heavily on the recommendations of international agencies and committees. Two of the most important of which are the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

The ICRP consists of a group of twelve scientists — biologists, physicists, geneticists, biophysicists, biochemists, and radiologists — who are selected by the International Congress of Radiology on the basis of their scientific reputation. The Commission is independent of all governments and political bodies and is accountable only to the International Congress of Radiology. Its recommendations have been adopted widely by all major countries as a basis for the protection of the public, and especially workers exposed to higher levels of radiation, from all sources of radiation.

The UNSCEAR was set up by the General Assembly of the United Nations in 1955 and reports to the International Atomic Energy Agency. It reviews the levels of radiation from all known sources and considers the scientific evidence related to the effects of various dose levels. In the United States, in 1972, another group of experts, the Biological Effects of Ionizing Radiation Committee (BEIR) was established by the National Academy of Sciences.

It is clear that the health hazards of radiation from all causes have been subjected to intensive research for at least twenty-five years and to other studies for many years before that. The level of confidence in the radiation standards that have been recommended and adopted should, therefore, be high. On the other hand, the standards are continually being challenged, which is a very healthy sign.

The ICRP has recommended that the total dose to the general population from all sources of radioactivity, additional to the natural background and to medical diagnostic exposures, should be limited to 5 rems per person per generation (30 years). Averaged over thirty years, this amounts to a limit of 170 millirems per person per year. Many authorities consider this rate to be much too high — and argue that if the whole population were exposed to this additional level of radiation, substantial health damage would be expected.

In reality, the average exposure of the population should never reach that level, assuming that the regulations governing the maximum radiation levels at the boundary of each nuclear generating station are strictly followed. In Canada, for example, the maximum whole-body dose for a person at the station boundary is limited to 500 millirems per year by the Canadian Atomic Energy Control Board regulations. The allowable doses for nuclear workers in Canada is ten times higher than the general population level and is set at a maximum of 5 rem per year.

Furthermore, the total exposure of the "population as a whole" is limited to 10^4 man-rem per year. The major dose to which this total population would be exposed would, of course, occur within about five miles of the generating station boundary.

Under accident conditions, the allowable dose at the site boundary may be appreciably larger than the standard dose. In Canada, under extreme accident conditions the maximum individual dose at the site boundary must be limited to 25 rem and the integrated all-body population exposure must be limited to 10^6 man-rem. The radiation standards, recommended by the ICRP for the exposure of nuclear workers and the public to ionizing radiation are given below. Under normal operating conditions, the historic releases of radioactivity at Ontario Hydro plants has generally been less than 1 per cent of the limits set by the AECB.

Standards for exposure to ionizing radiation (1977) — rems per year

Gonads and bone marrow	
Nuclear workers	5
Public	0.5
Skin, thyroid, bone	
Nuclear workers	30
Public	3
Hands, feet	
Nuclear workers	75
Public	7.5
All other organs	
Nuclear workers	15
Public	1.5

Source: Based on data from ICRP.

Postscript

Some health physicists regard the 5 rem per year dose limit for nuclear workers to be much too high. Professor Edward Radford of the Graduate School of Public Health, at the University of Pittsburgh has advocated a reduction of the 5 rems limit to 0.5 rem. However, he considers that, in certain special circumstances, the limit might be increased on an individual basis, although never to more than 5 rems per year. Professor Radford, who is chairman of the BEIR Committee, has pointed out that "a worker exposed to 5 rem annually for 30 years is at about twice the risk of cancer as a person not exposed." It is clear that much more work is needed on the risk implications of exposure to radiation. In the meanwhile we strongly endorse the view that the exposure levels to which workers are subjected should be reduced to an absolute minimum.

Annex E

The Non-Nuclear Options for Ontario

The province's electric power system is based on a diversity of generation technologies — hydroelectric, fossil-fuelled (coal, oil and natural gas) and nuclear generating stations. Since the beginning of the century the system has been evolutionary and it continues to be so. Ontario's future commitment to nuclear power should, of course, be viewed in the light of what we have called the "non-nuclear options". Although we cannot do the subject justice in an Annex (it will be treated in depth in our final report), we believe it is important to give some indication of the state of the art with respect to the most important of these options.

Anticipated shortages of oil and natural gas, probably before the turn of the century, and the inevitability of long lead times in the development of viable replacements on an adequate scale, have led us to conclude that the province's indigenous resources could be particularly significant in reducing our reliance on oil. We review some of the options below.

Hydraulic Systems

Hydroelectric power has played and continues to play a central role in the generation of electricity in Ontario. After the success of the Niagara Falls hydroelectric project at the beginning of the century, a series of major developments have harnessed all the major rivers in Southern Ontario; at present, the province has about 7000 MW of installed hydraulic generating capacity,[1] of which roughly 40 per cent is used to meet base load requirements.

Potential hydroelectric developments, of greater than 10 MW installed capacity, are estimated at about 3600 average annual MW.[2] But a major portion of this hydraulic power potential is located in Northern Ontario. For cultural, environmental and economic reasons, it is not anticipated that the potential of the Albany, Severn, and Winisk river systems will be developed during the next twenty years. However, even without the development of these river systems, a significant amount of electricity could be produced from the Moose River system and from extensions to existing facilities. Preliminary results of a recently completed Ontario Hydro study of suitable sites suggest that roughly 1650 MW of installed capacity could be made available between 1982 and 1994.[3] Through the installation of new turbines, raceways, for example, Ontario Hydro is already upgrading several existing hydroelectric stations. When completed, approximately 200 MW of installed capacity will be added.[4]

Small scale hydraulic generation of electricity in Ontario is a substantial and usually environmentally acceptable renewable energy source. A number of potential sites exist throughout the province. For example, about 470 sites, originally developed to generate mechanical and electric power, were removed from service in recent years because of high operating and maintenance costs. Some of these sites could be recommissioned. An additional 500 sites remain undeveloped; indeed, Ontario Hydro has estimated that these sites could deliver approximately 700 average annual MW. However, the utility maintains that the major portion of this potential will remain undeveloped because of recreational and tourism interests and, in some instances, because of technical or environmental difficulties.[5]

Given adequate incentives, it is reasonable to expect the private sector to take an interest in this hydraulic resource potential. In the United States, for instance, the Department of Energy is sponsoring a Low Head Hydro Power Program to assist and encourage the private and non-federal public sectors to develop hydroelectric resources at suitable existing dam sites, with emphasis on those sites with a capacity of between 50 kilowatts and 15 megawatts.[6] Another objective of the Department is to encourage utilities to install hydroelectric generators at new dam sites suitable for low

head hydroelectric power production. In Ontario, assuming rehabilitation of some decommissioned small-scale hydroelectric generating sites and the development of some new sites, a significant amount of electricity could be obtained by pursuing a similar approach. Ontario Hydro is already working closely with the native peoples of Northern Ontario, through Grand Council Treaty Number 9, to develop 100 to 200 kW hydraulic turbines for use in remote locations.

Further development of hydraulic potential may result from the initiative of some industries. One example is the proposal by INCO Metals Company to develop 80 to 120 MW of hydroelectric capacity on the Spanish River.[7] The INCO programme would reduce demand on the provincial power grid and allow greater resilience for both the industry and the utility system. Many industries feel that there will be a trend towards the utilization of small scale hydroelectric projects because they offer reliable power supplies. Hydraulic generation may also supply both base load and peak load requirements.

Coal

The increased utilization of Canada's coal resources will play an essential role in Ontario's energy future. This will necessitate, for example, the development of more elaborate coal transportation systems including coal slurry pipelines and unit trains. In the past, dependence on coal has given rise to a number of environmental hazards. However, technologies are available which will reduce the potential harmful effects of coal fuels. These include fluidized bed combustion, coal liquefaction, coal gasification, and new combustion systems employing a variety of fuels in combination with coal. Furthermore, new ways of controlling emissions have been developed and may play a key role in certain parts of the province, especially near heavily populated areas.[8]

Energy, Mines and Resources Canada has estimated that total Canadian coal production will be 118.1 million tons (107.1 metric tonnes) annually by 1990.[9] Ontario's only known coal resource is the Onakawana lignite deposit in Northern Ontario with estimated reserves of up to 200 million tonnes. The coal alternative for Ontario implies a careful examination of the economics of importing coal into the province as well as an analysis of mining and transportation costs associated with the utilization of the province's indigenous supply. The social and environmental implications of a possible development of the Onakawana lignite reserves is at present being studied by the Royal Commission on the Northern Environment.

Oil and Natural Gas

Oil and natural gas are major Canadian resources and are likely to remain so for at least the next fifty years, if we assume large scale development of the tar sands and offshore deposits. Although Ontario Hydro is not anticipating increased use of oil and natural gas in bulk power generation, these resources will clearly play an important part in Ontario's overall energy policy, thereby affecting the demand for electricity.

Energy from Biomass

Potential sources of biomass suitable for energy conversion include forest industry wastes, agricultural wastes, municipal solid wastes, and peat, as well as forests dedicated to energy production. The idea of utilizing wood and biomass as a source of energy is not new. What is new is the recognition of the vast potential of wood energy, resulting from the development of new tree species and new transportation, handling, and combustion techniques.

In a brief to the Commission, Fisheries and Environment Canada stated that:

> In Ontario, 198,636,000 acres (79,454,400 hectares) of land are classified as forested. Of this 60,703,000 acres (24,281,200 hectares) are available for the production of forest products. If an intensive energy forest programme were initiated, it is reasonable to assume that 6,070,300 acres (2,428,120 hectares) or 10 per cent of this land could provide enough biomass for approximately 10,000 MW of installed generating capacity or 4 billion gallons of methanol.[10]

The brief argues that, simply by using wood residues with current technology, enough fuel exists now in Ontario to supply fifty power stations of 50 MW capacity. Although these estimates may be somewhat optimistic, trees and plants are renewable resources and consitute a viable alternative

energy source. Of special interest is the fact that the Ontario Ministry of Natural Resources has developed a new species of hybrid poplar which can be grown quickly, harvested, and used to fuel thermal electric generating stations. Experiments are now under way to determine if large scale plantations of this hybrid poplar, dedicated solely to use as fuel for electric generating stations, would be viable. A feasibility study undertaken for the Commission by consultants concludes that, through the acquisition of abandoned Eastern Ontario farmland, enough trees could be grown to fuel 1600 MW of wood-fired generating capacity by 1995.[11] The utilization of dedicated forest potential is a longer term option for Ontario requiring fifteen to twenty years development. Further studies now under way will be reviewed in the Commission's final report.[12]

On a smaller scale, some industries could use wood wastes to supply a large portion of their total energy requirements. The pulp and paper industry, for example, the largest energy consumer in Canada's industrial sector, consumes almost 14 per cent of the electricity used by the industrial sector in Ontario. It is unquestionably in a strong position to capitalize on biomass energy, not least because about one-third of the wood harvested for pulp, paper, and lumber production is left as mill wastes. Combustion of these wastes could provide low grade heat or steam for use within the industrial plant process, and could be coupled with electricity generation, either for internal use or for sale to the provincial electrical grid. This concept is not merely wishful thinking on the part of "amateurs"; at least one major forest products company in Ontario is enthusiastic about it and has used it for several years. Indeed the majority of pulp and paper companies, because of escalating prices of oil and electricity, are demonstrating that the day when they will be essentially energy self-sufficient may not be far off (perhaps within fifteen to twenty years).

Garbage and organic wastes provide another source of biomass energy. The "Watts from Waste" project being undertaken jointly by Ontario Hydro and Metropolitan Toronto is an example of one scheme to convert combustible municipal wastes to useful energy. Several major U.S. cities are already converting a high percentage of their combustible municipal waste as well as recycling the glass and ferrous metal components. This approach to energy conservation is clearly worthy of in-depth study, not least as a means of dealing with the municipal waste disposal problem. In addition, some of the organic wastes produced on Ontario farms could provide a significant fuel for energy conversion. Organic waste matter ferments to produce combustible gases (e.g. methane) which can be used as gaseous or liquid fuel.

There are other biomass possibilities, such as the production of ethanol and methanol, which are being used in some countries as gasoline additives. However, these are long term prospects and are unlikely to have much impact in Ontario before the end of the century.

Solar Energy

A number of estimates have been made of the potential penetration of solar heating systems in Ontario; these range from 3 per cent of total energy to an overly optimistic 10 per cent by the year 2000.[13] Depending upon government incentives it is possible that approximately half of all new dwellings in Ontario could have "active" solar space heating by the year 2000, and that the remainder would capitalize on "passive" solar heat. However, even with a significant degree of solar utilization in the commercial and industrial sectors, the Commission anticipates that solar energy will contribute no more than 3 to 5 per cent of total energy required by the year 2000.

Wind Energy

During the information and debate stage hearings there were many references to the potential of wind energy generators for the generation of electricity. However, with the possible exception of certain locations in Northern Ontario, the scope for wind energy in Ontario is not particularly promising because the average wind velocities in most locations are below those regarded as marginal for the extensive use of this source of energy. Nevertheless, research and development programmes are being continued.

Other Technologies

There are many other potential energy conversion technologies that may become viable for Ontario after the turn of the century. Noteworthy are solar photovoltaic and chemical conversion, fusion power, and magnetohydrodynamics. A major obstacle to their development at this time is a materials problem. The Commission supports further research and development into these important future energy resources.

In addition, there are a number of technologies which can be used to increase efficient utilization of existing energy supplies. Co-generation, energy storage systems, and the heat pump, to name a few, are examples of technologies which are currently applicable to Ontario.

Co-generation

The co-generation of thermal energy — in the form of process steam for industry or hot water for district heating — as well as electricity, is in wide use in various European countries. As an energy conversion process, it is about twice as efficient as either conventional nuclear or fossil-fuelled electric power generation. Possible primary fuels are natural gas, oil, coal, wood, and municipal wastes. A co-generation plant could be based on gas turbines, fluidized bed combustion, and coal-wood fuelled boilers. One major Ontario chemical company has been pioneering the use of co-generation for several years, but to date this process has not been developed on a broad commercial basis,[14] although this situation is rapidly changing as both industries and governments realize the importance of maximizing efficient utilization of conventional fuel supplies.

Capacity Management — Energy Storage Systems

Energy storage systems can be used by an electric utility to reduce its requirements for on-line capacity or to lower its need to employ higher cost units to meet peaks in demand. There are a number of approaches to retaining energy for electric generation, including: pumped hydraulic, compressed air, fly-wheel, thermal, battery, chemical, and super conducting magnetic storage. To assess the potential for energy storage, a utility must determine the amount of off-peak energy that could be available for charging energy storage devices, as well as the amount of on-peak energy that can be supported by the stored energy. Above-ground pumped storage at the Sir Adam Beck station on the Niagara River is the only large scale energy storage method now used by Ontario Hydro. We have concluded that to optimize the utilization of Ontario's energy resources, the province should encourage the development of additional energy storage technologies where applicable.

Heat Pumps

The principle of the heat pump has been known for many years. In effect, a heat pump operates on the same general principle as the domestic refrigerator. During the summer months, for example, a heat pump can operate as an air-conditioner. During the winter months a heat pump extracts heat from a large space (this is always low quality thermal energy) and injects the thermal energy into the space to be heated. If the ambient temperature is in the range of about -4°C to 16°C, commercially available heat pumps can improve the efficiency of an electric heating supply by at least 50 per cent. However, a heat pump particularly suitable for winter conditions in Ontario could be designed to operate with appreciably lower ambient temperatures, providing further gains in efficiency. Obviously, capital is required to purchase and install heat pumps but in the longer term (five to ten years), because of savings in electric energy utilization, the system would be economically viable.

Annex F

Reprocessing and Disposal Options

Annex G

Status of Power Reactor Licensing in Ontario

Facility Name Licensee	Type and Capacity	Status and Remarks
NDP Generating Station, Rolphton, Ontario (Ontario Hydro and AECL)	CANDU-PHW 20 mw(e)	Started up 1962. Licence duration May 29, 1978 to June 30, 1983. Licenced for full power operations. New arrangement for the calandria spray cooling circuit installed in 1977. Additional design changes to increase the effectiveness of Emergency Core Cooling System are being implemented or are under review.
Douglas Point Generating Station, Tiverton, Ontario (Ontario Hydro and AECL)	CANDU-PHW 200 mw(e)	Started up 1966. Licence duration July 5, 1977 to June 10, 1982. Operating licence: on March 25, 1977, derated to 70 percent of full power pending completion of modifications to the Emergency Core Cooling System.
Pickering Generating Station "A", Pickering, Ontario (Ontario Hydro)	CANDU-PHW 4 x 500 mw(e)	Started up 1971. Licence duration June 30, 1977 to June 30, 1982. Operating licence: operating at full power with additional operating procedures in effect relating to the Emergency Core Cooling System. These procedures will be replaced with design changes currently being installed on the four reactors.
Bruce Generating Station "A", Tiverton, Ontario (Ontario Hydro)	CANDU-PHW 4 x 750 mw(e)	Units 1 and 2 started up 1976; unit 3 in 1977. Licence duration November 21, 1977 to September 30, 1978. Operating licence: operating at 88 percent of design full thermal power (producing 100 percent of rated electrical power). Unit 4 under construction. Construction licence dated November 21, 1977.
Pickering "B", Pickering, Ontario (Ontario Hydro)	CANDU-PHW 4 x 500 mw(e)	Construction licence 1974. Start-up expected 1981. Undergoing a review to insure that overall regulatory requirements are to be met.
Bruce "B", Tiverton, Ontario (Ontario Hydro)	CANDU-PHW 4 x 750 mw(e)	Construction licence 1975. Start-up expected 1983. Undergoing a review to insure that overall regulatory requirements are to be met.
Darlington (Ontario Hydro)	CANDU-PHW 4 x 850 mw(e)	Site approval granted June 9, 1975. Construction licence application being prepared for Atomic Energy Control Board. Public information programme underway. Start-up expected 1986. Undergoing a review to insure that overall regulatory requirments are to be met.

Glossary

Actinide – Heavy elements with an atomic number greater than 89. The series includes, actinium, thorium, protactinium, uranium, neptunium, plutonium, americium, curium, berkelium and californium, all of which are chemically very similar; actinides of interest are those which are long half-life alpha-emitters.

AECB (Atomic Energy Control Board) – Federal government body that regulates the use of atomic energy in Canada. (Licensing body.)

AECL (Atomic Energy of Canada Limited) – Crown Corporation involved in research, development and demonstration of nuclear energy in Canada.

Alpha particle – A heavy particle produced by a radioactive decay process and in various nuclear reactions. It consists of two protons and two neutrons and thus carries two positive charges. It is identical with the nucleus of a helium atom.

Atom – The basic building block of all substances, which cannot be broken down further by chemical means. Each has a nucleus surrounded by one or more orbital electrons. Each element has its own distinctive arrangement of electrons and protons in its atom.

Atomic number – The number of protons in the nucleus of an atom. Each element has its own distinctive atomic number.

Background radiation – The natural ionizing radiation of man's environment including cosmic rays from outer space, naturally radioactive elements in the ground, and naturally radioactive elements in a person's body.

Base load – Generation capacity that is required most of the time, independent of peaking, etc. In Ontario the base load is generated mainly by hydraulic and nuclear sources. Ontario Hydro defines base load as that load which is met by generating stations operating at a capacity factor of 55% or more on an annual basis.

Beta particle – A light particle produced in many nuclear reactions and in radioactive decay processes. It may carry a negative or positive charge, but in common usage the term refers to the negatively charged particles, which are identical to electrons.

Biomass energy – Energy fixed in organic matter by photosynthesis — e.g., burning wood, algae, agricultural biomass.

Bituminous coal – A high-quality coal with a high percentage of pure carbon, low ash and low moisture content, with a heat content of approximately 11,000-13,000 Btu/lb.

Boiling Water Reactor (BWR) – A nuclear power reactor cooled and moderated by light water. The water is allowed to boil in the core to generate steam which passes directly to the turbine.

Breeder reactor – A type of reactor in which the number of fissile nuclei produced (bred) from fertile nuclides is greater than the number of fissile nuclei concurrently destroyed. The type of breeder reactor currently being developed produces plutonium-239 derived from uranium-238, while consuming plutonium-239 and uranium-235.

Btu (British thermal unit) – A standard unit of heat used in measuring the available heat energy of fuels.

Burn-up – A measure of the quantity of energy that has been obtained from a sample of nuclear fuel in a reactor core. It also determines the quantity of fission products produced and hence influences the level of radioactivity of the spent fuel. Burn-up is usually measured in units of megawatt-days per tonne of fuel.

Calandria – A cylindrical reactor vessel that contains the heavy water moderator. Hundreds of tubes extend from one end of the calandria to the other, containing the uranium fuel and the pressurized high temperature coolant. The reactor core consists of all of the components within the calandria.

CANDU – A Canadian-developed nuclear power reactor system. The name is derived from CANada Deuterium Uranium, indicating that the moderator is deuterium or heavy water and the fuel is natural uranium. Pressure tubes containing the fuel and coolant run the length of the reactor vessel or calandria.

Capacity factor – The ratio of the amount of electrical energy actually generated by a power station in a given period to the amount of electricity which would have been generated if the power station had been operating at full capacity throughout the period.

Chain reaction – A reaction that initiates its own repetition.

China syndrome – Possible consequence of core meltdown, when a molten mass of intensely radioactive material plummets through vessel and containment and into the earth beneath in the direction of China (unless the reactor is in, say, Japan).

Coal gas – A form of natural gas produced from coal. It has a low Btu content.

Commercial in-service date – The date at which a new unit has completed its testing and is turned over to the operators for normal system operation.

Committed – A committed project is one which has been authorized and for which a release has been issued for work on final design, acquisition and construction.

Common-mode failures – A failure of two or more components due to an identical fault in each component.

Containment – The structures, within and including the reactor building, designed to prevent any material that may escape from the reactor itself from reaching the outside environment. The reactor containment usually consists of steel and thick concrete.

Contamination – Radioactivity where it should not be.

Control rod – Rod of neutron-absorbing material inserted into reactor core to soak up neutrons and shut off or reduce rate of fission reaction.

Conversion ratio – Number of fertile nuclei converted to fissile, compared to number of fissile nuclei lost by undergoing fission.

Coolant – A liquid or gas circulated through the core of a reactor to extract the heat of the fission process.

Core – The central part of a nuclear reactor containing the fuel rods, moderator and control rods. The nuclear fission reactions take place and the resultant heat is generated within the core.

Cost-benefit analysis – A technique that attempts to set out and evaluate the social costs and social benefits of projects to help decide whether the project should be undertaken. The essential difference between cost-benefit analysis and ordinary investment appraisal methods is the stress on social costs and benefits.

Critical – Refers to a chain reaction in which the total number of neutrons in one 'generation' of a chain reaction is the same as the total number of neutrons in the next 'generation' of the chain; that is, a system in which the neutron density is neither increasing nor decreasing.

Critical mass – The minimum amount of fissile material needed to sustain a chain reaction. It depends on the geometry and enrichment of the material and the presence of a moderator.

Criticality – The instantaneous condition when a sufficient mass of a fissile material assembled in the right shape and concentration begins a self-sustaining chain reaction.

Cross-linked failures – Coincident or overlapping failures of systems due to failures of shared supply systems or control systems, etc.

Curie – Measure of the rate at which radioactive material disintegrates, which correspond to 37,000 million radioactive emissions per second: radioactivity of 1 gram of radium.

Daughter/Daughter product – The substance into which a radioactive nucleus transforms itself by radioactive decay.

Decay – The decrease in activity of a radioactive material as it spontaneously transforms from one nuclide to another or into a different energy state of the same nuclide.

Decay heat – Heat generated by radioactivity in the fuel of an operating reactor; additional to heat from chain reaction, and cannot be shut off.

Decontamination – Transfer of unwanted radioactivity to a less undesirable location.

Demand – The amount of electric power or energy consumed by customers. See Load.

Demand-elasticity – A measure of the degree to which consumption of a good or service changes with a change in its price or with a change in the income of potential consumers or with a change in the price of substitute goods and services.

Depreciation – An annual charge that recovers the original cost of a capital facility over its estimated useful service lives in a systematic manner.

Deuterium – An isotope of hydrogen containing one proton and one neutron in the nucleus. Chemically it is similar to hydrogen but it has different physical and nuclear properties. Its natural abundance is about one part in 7,000 of hydrogen. In the form of heavy water (D20) it is the most effective neutron moderator available for reactors.

Discount rate – A rate of interest representing the time-related value of resources. It is used to convert costs that occur at any given time to equivalent values at a specified time, for comparison purposes.

Discounted cash flow – A method of appraising investments based essentially on the ideas that the value of a specific sum of money depends on precisely when it is to be received.

Disintegration - See Decay.

Diversity - The difference between the sum of the non-coincident maximum demand of individual customers and the coincident peak load for the group.

Dose - Amount of energy delivered to a unit mass of a material by radiation travelling through it.

Dose-Rate - Time rate at which radiation delivers energy to unit mass of a material through which it is travelling.

East System - Ontario Hydro's facilities in the area lying roughly east of Wawa.

Elasticity of demand - See Demand-elasticity

Electric power - Rate of transfering electric energy, expressed in units of kilowatts or megawatts.

Electron - Negatively charged particle; much lighter than proton or neutron.

Energy demand - The average power required to supply the load over a stated interval of time.

Enriched uranium - Uranium in which the content of the fissile isotope, uranium-235, is higher than the 0.71% normally found in nature. Low enriched uranium, containing 2-4% of uranium-235, is used as fuel in many types of reactor. High enriched uranium, which may contain more than 90% uranium-235, is used as fuel in some types of reactor and also to make nuclear weapons.

Equity - The excess of assets over liabilities. Ontario Hydro's equity consists of funds provided by customers in the price payable for power, and the contributions from the Province of Ontario as assistance for rural construction.

Escalation - The increase in unit prices of equipment, material and labour from one year to the next.

Exclusion area - Area around a nuclear facility in which no permanent habitation is allowed.

Fast reactor - A type of nuclear reactor in which the concentration of fissile nuclei in the fuel is so high that the nuclear reaction can be sustained by fast (i.e., unmoderated) neutrons.

Fertile material - Material that is transformed into fissile material by neutron capture.

Firm power - Power available for use by the purchaser on a commercially continuous basis.

Fissile material - Material that will fission when struck by a neutron.

Fission - The process by which a nucleus splits into two approximately equal fragments plus several free neutrons, giving off large amounts of energy which appears as the energy of gamma radiation and heat. Fission occurs spontaneously in certain heavy elements, but the kind of fission making chain reactions possible occurs when a fissile nucleus absorbs a neutron.

Forced outage - Outage caused by the breakdown or loss of a major system component.

Forward contract - A contract signed now for delivery in the future.

Fuel bundle - An assembly of metal tubes containing nuclear fuel pellets ready for insertion in a reactor.

Fuel pellets - Uranium dioxide, or other nuclear fuel in a powdered form, which has been pressed, sintered and ground to a cylindrical shape for insertion into the sheathing tubes of the fuel bundle.

Fuelling machine - Equipment used to load and unload fuel bundles. CANDU fuelling machines are remotely controlled and load the fuel while the reactor is operating.

Fuel sheath - Tubing into which fuel pellets are inserted and sealed to make a fuel element. A number of elements are assembled to make a fuel bundle.

Fusion - Short for thermonuclear fusion, a type of nuclear reaction in which two light nuclei, such as deuterium, fuse together to form one heavier nucleus, in the process releasing a large amount of energy. Fusion reactions only take place at exceedingly high temperatures. They are the source of the energy given off by the sun and also of most of the energy released when a hydrogen bomb explodes.

Gamma ray - A form of electromagnetic radiation, similar to light or x-rays, distinguished by its high energy, high penetrating power and short wave length. Gamma radiation is emitted from many nuclei when they are undergoing radioactive decay and in many other nuclear reactions.

Gas-cooled reactor - A nuclear reactor in which a gas, suçh as carbon dioxide, is used as the coolant.

Genetic effects - Effects produced by radiation in the offspring of the person irradiated, usually malformations.

Geothermal power - Recovery of energy from subsurface warm water supplies (naturally occurring geysers, etc.).

Grid - In the utility context, an interconnection of electric circuits.

Gross margin - The difference between dependable capacity and primary demand.

GWe - Abbreviation for "gigawatt electrical." One GWe is equal to one thousand megawatts electrical (1000MW(e)).

Half life – The time taken for half the atoms of a radioactive substance to disintegrate; hence the time to lose half its radioactive strength. Each radionuclide has a unique half life ranging from a millionth of a second to billions of years.

Heat exchanger – A piece of apparatus that transfers heat from one medium to another. A typical example is the steam generator in the CANDU system where the hot pressurized heavy water coolant is used to convert ordinary water into steam to run the turbine.

Heavy water – Water in which the hydrogen atoms are the heavy hydrogen isotope, deuterium. It is sometimes called deuterium oxide and occurs in natural water to the extent of about 1 part in 7000.

High level waste – The most highly radioactive waste from fuel reprocessing and the nuclear cycle containing most of the fission products from spent fuel and typically containing millions of curies per cubic metre when first separated. It also contains small amounts of unseparated uranium and plutonium plus the greater proportion of the other actinides produced in the reactor.

HTGR – High temperature gas cooled reactor.

Interest capitalization – An accounting procedure whereby the cost of a fixed asset includes an allowance for the use of funds employed during the construction of the asset. Also, the amount credited to the income of the enterprise to offset the cost of capital employed during construction.

Intermediate level waste – A somewhat arbitrary classification of part of the waste from fuel reprocessing and the nuclear cycle typically containing thousands of curies per cubic metre.

Intermediate load – Load supplied by generating capacity operating at annual capacity factors between 10% and 55%.

Iodine – As Iodine-131; biologically hazardous fission product of short half-life (8 days) which tends to accumulate in the thyroid gland.

Ion – See Ionizing Radiation.

Ionizing Radiation – Radiation which, by reason of its nature and energy, interacts with matter to remove electrons from (ionize) the atoms of material absorbing it, producing electrically charged atoms which are called ions.

Irradiated – Reactor fuel, having been involved in a chain reaction, and having thereby accumulated fission products; in any application, exposed to radiation.

Isotope – Atoms of an element having the same number of protons in their nuclei but different numbers of neutrons are called isotopes. All isotopes of an element have the same chemical properties and thus cannot be separated by chemical means. However, they can be separated by using certain physical processes, such as gaseous diffusion.

Kilowatt (kW) – One thousand watts; a unit of electric power.

Kilowatt hour (kWh) – A unit of energy equal to the work done by one kilowatt acting for one hour.

Lead time – Time required to plan and construct a facility, including time required to obtain government approval, carry out environmental assessment, etc.

Lignite – A low-quality type of coal which has a high moisture content and high ash content with a heat content of approximately 5000-7000 Btu/lb., midway between bituminous coal and peat.

Load – A device that receives power, or the power delivered to such a device. Also, the amount of power or energy consumed by customers.

Load factor – **The ratio of average power demand to peak power demand in a given time period.**

Load forecast – A prediction of the load to be experienced at some point in the future.

Load growth – The rate of growth of electric energy utilization (usually expressed as a percentage).

Low Level Waste – Part of the waste from various stages of the nuclear fuel cycle typically containing a few curies per cubic metre.

LWR – Light water reactor.

Magnetohydrodynamics – A direct energy conversion system in which a hot gas system is seeded with an alkali metal and ionized. Technology is in a developing state. Highly efficient when combined with a conventional steam turbine cycle.

Mega – Mega is the prefix attached to volts, watts or watthours indicating the quantity or magnitude in units of a million.

Megawatts (MW), MW(e), MW(th) – One megawatt is a unit of power equal to one thousand kilowatts. MW(th) denotes the thermal power of a power station, that is the rate at which heat is produced (by fission in the reactor core if it is a nuclear power station). MW(e) denotes the electrical power output of the station and is only a fraction of the thermal power — typically about 30% for a heavy water reactor and up to 40% for a modern fossil fuel-powered station. This ratio is also called the thermal efficiency of the power station.

Meltdown – Reactor core; consequence of overheating which allows part or all of the solid fuel in a reactor to

reach the temperature at which cladding and possibly fuel and support structure liquefy and collapse.

Mills/kilowatthour – The terminology used to indicate the cost of electrical energy produced by a generating station: a mill is one-thousandth of one dollar and a kilowatthour is the standard unit of energy produced or consumed.

Mixed oxide – Reactor fuel; fuel in which the fissile nuclei are plutonium-239, mixed with natural or depleted uranium in a proportion equivalent to enriched uranium.

Moderator – A material used in a reactor core to slow down fast neutrons, without unduly absorbing them, so as to increase the probability of the neutrons causing fission in a uranium-235 or plutonium-239 nucleus.

Natural uranium – Uranium whose isotopic composition as it occurs in nature has not been altered (0.71% by weight of U-235).

Neutron – An uncharged particle which is a constituent of the nucleus of all nuclides except hydrogen; neutrons are ejected from the nucleus in nuclear reactions, such as fission.

NPT (Non-proliferation treaty) – Intended to control the spread of nuclear weapons and their technology.

Nuclear energy – The energy liberated by a nuclear reaction such as fission.

Nucleus – The positively charged core of an atom which has almost the whole mass of the atom but only a minute part of its volume. All nuclei are made up of protons and neutrons, except for ordinary hydrogen (H) which contains only one proton.

Nuclide – A nuclear species, all the atoms of which contain similar nuclei.

Once-through – Term used in the utility context for: *a*) once-through cooling - use of process cooling water only once, i.e., in-out; *b*) use of uranium fuel in a reactor only once, i.e., the fuel would not be reprocessed.

Organic coolant – An oil-like liquid having a high boiling point at low pressure used as coolant in the WR-1 test reactor at the Whiteshell Nuclear Research Establishment of AECL in Manitoba.

Outage – A failure of the electric power system.

Peak load – The highest average load during a time interval of specified duration, e.g., 20 minutes, occurring during a given period of time, e.g., in a day.

Peak load generation – Generation whose energy output is produced chiefly during periods of greatest electricity demand. This generation is utilized only 5 to 10% of the time.

Planned outage – An outage which can be postponed from one season to another, usually for major overhauls.

Plutonium – Heavy artificial metal, made by neutron bombardment of uranium; fissile, highly reactive chemically, extremely toxic alpha-emitter.

Poison – Any non-fissionable, non-fertile substance in a reactor with a high capacity for neutron capture that decreases reactivity. Poisons are deliberately introduced to adjust the level of fission or to shut down the reactor.

Power – The rate of doing work, or in an electrical network the rate at which electrical work is supplied. Sometimes the word is used in a general sense, to cover both power and energy.

Pressure tube reactor – A power reactor in which the fuel is located inside hundreds of tubes designed to withstand the circulation of the high pressure coolant. The tubes are assembled in a tank containing the moderator at low pressure. (See CANDU.)

Pressurized Water Reactor (PWR) – A power reactor cooled and moderated by light water in a pressure vessel surrounding the core. The water is pressurized to prevent boiling in a closed primary loop and is circulated through a heat exchanger which generates steam in a secondary loop connected to the turbine.

Primary demand – The sum of firm demand and interruptible demand.

Proton – A positively charged particle which is a constituent of the nucleus of all nuclides. The number of protons in the nucleus determines the chemical properties of an element and hence is characteristic of each of the chemical elements.

Rad – The unit dose of ionizing radiation. One rad is absorbed when 100 ergs of energy is imparted to each gram of matter by ionizing radiation (See Rem.)

Radiation – The emission and propagation of energy through space or matter in the form of electromagnetic waves (e.g. gamma and x-rays), and fast moving particles (e.g. alpha and beta particles).

Radioactivity – The spontaneous decay of an unstable atomic nucleus into one or more different elements or isotopes. It involves the emission of particles of spontaneous fission until a stable state is reached. Note that radioactivity produces radiation - the two terms are not equivalent.

Reactivity – A measure of the departure of a reactor from criticality. A positive value means that the release of neutrons is increasing and the power will rise,

while a negative value means that the release of neutrons is decreasing, the power is falling and the chain reaction could die out.

Reactor – An assembly of nuclear fuel that can sustain a controlled chain reaction based on nuclear fission.

Recycling – The stage in the nuclear fuel cycle (not yet achieved on a commercial basis) in which uranium and plutonium extracted from spent fuel are returned to an earlier stage of the fuel cycle for reuse in fresh fuel rods.

Reliability – The degree of continuity of supply.

Rem – The abbreviation for Roentgen equivalent man, the unit of an absorbed dose of ionizing radiation in biological matter. It is the absorbed dose in Rads multiplied by a factor which takes into account the biological effect of the radiation.

Reprocessing – The stage of the nuclear fuel cycle (not yet achieved on a commercial basis except for magnox fuel) at which plutonium and uranium in spent fuel are separated from the other actinides and the fission products, which constitute waste.

Reserve capacity – The difference between the capacity of a system component (or group of components) and the maximum actual or expected demand placed upon it.

Scram – Emergency shutdown of fission reaction in a reactor.

Shielding – A mass of material that reduces radiation intensity to protect personnel, equipment or nuclear experiments from radiation injury, damage or interference.

Sinking fund – Provision for repayment of debt by means of accumulating money through regular payments which, with accumulated interest, may be used to settle the debt in instalments over time or in a lump sum.

Somatic effects – Effects produced by radiation in the body of the person irradiated, usually cancers.

Spent fuel – Nuclear fuel that has been irradiated in a reactor to the extent that it can no longer effectively sustain a chain reaction; i.e., the fissionable isotopes have been consumed and fission-product poisons have been accumulated.

Spot price – Price for immediate delivery of a commodity.

Tailings – The waste material from a uranium mill after the uranium has been extracted from the ore. Tailings contain the radioactive decay products of uranium mixed with a large volume of non-radioactive rock, all in a finely ground form and mixed with water.

Thermal plant – A station for generating electrical energy from thermal sources. A thermal plant may have fossil-fuelled steam turbines or fossil-fuelled combustion turbines or nuclear steam turbines.

Thermal plume – Shape that the heated discharge from thermal generating stations makes in the water.

Thorium – A heavy, slightly radioactive metallic element with an atomic number of 90, whose naturally occurring isotope Th-232 is fertile and the source, when irradiated in a reactor, of U-233.

Tonne – Metric ton; 1 metric ton = 2204.6 pounds

Tritium – A radioactive isotope of hydrogen with a nucleus containing one proton and two neutrons. It occurs naturally in minute quantities, but is produced as a byproduct of controlled nuclear fission. It is also produced, in relatively large quantities, by nuclear fusion.

Uranium – Heaviest natural element, dark grey metal; isotopes 233 and 235 are fissile, 238 fertile; alpha-emitter.

Waste heat – The non-usable heat primarily due to thermodynamic restrictions on efficiency.

Watt – Unit of electrical power, represents the power used when one ampere flows through a circuit with a pressure of one volt.

West System – Ontario Hydro's facilities in the area lying roughly west of Wawa.

Yellowcake – Mixed uranium oxides, with formula U-3O8, produced from uranium ore by extraction process in uranium mill.

Zircaloy – Alloy of zirconium used as fuel cladding; has low cross-section for absorption of neutrons.

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